New diagnostic and therapeutic possibilities in the treatment of elbow and distal forearm fractures in childhood

PhD THESIS

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University of Szeged
Doctoral School of Clinical Medicine

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List of publications related to the subject of the thesis

I. Intraoperative sonography may reduce the risk of extensor pollicis longus tendon injury
during dorsal entry elastic intramedullary nailing of the radius in children
Varga, M; Gáti, N; Kassai, T; Papp, S; Pintér, S
Medicine (Baltimore), 2018 vol. 97(24) pp. e11167
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II. Ultrasonographic diagnosis of distal paediatric forearm fractures
Varga, M; Gáti, N; Kalóz, E; Bíró, Z; Szeverényi, C; Kardos, D; Józsa, G
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III. Short, double elastic nailing of severely displaced distal paediatric radial fractures: A new method for stable fixation
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V. Nagy diszlokációval járó disztális gyermekkori radius metaphysis törések kezelése rövid elasztikus velőűrszegezési technikával
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Varga, M; Kassai, T; Bíró, Zs; Kalóz, E; Józsa, G; Gáti, N; Pintér, S;

List of abbreviations in the text

US	ultrasound
PoCUS:	point of care ultrasound
MSK-US:	musculoskeletal ultrasound
IoP-MSK US	intraoperative musculoskeletal ultrasound
PE	pulled elbow
EPL	extensor pollicis longus tendon
LH	lipohemarthros
FPS	fat pad sign
eFPS	elevated fat pad sign
ED	emergency department
MHz	megahertz
SCH fracture	supracondylar humeral fracture
SFE	synovial fringe enlargement

Contents

Introduction

Fractures of the elbow and distal forearm are among the most frequent injuries in children. (1,2,3) The spectrum of these injuries is very wide from small contusions without clinical consequences to severely displaced fractures with limb threatening conditions. (4) Primary diagnosis and treatment are often performed by emergency physicians, general practitioners or paediatric surgeons. (5) Indications of unnecessary imaging procedures, under- and over-treatment may occur by less-specialised healthcare personnel. (5) Recognising certain elbow fractures may be a challenge even for an experienced orthopaedic surgeon due to the special characteristics of childhood. (6) Certain distal forearm and elbow fractures may not be detected by conventional X-rays. (7,8,9) The evaluation of severely displaced distal radius fractures and setting up a plan for further treatment may be particularly difficult due to the lack of therapeutic consensus. (10) In recent years, there have been a growing evidence that musculoskeletal ultrasound (MSK-US) can increase the effectiveness of diagnostics and may reduce the number of unnecessary X-rays. (11) Elastic intramedullary nailing of displaced distal radius fractures may have many advantages over traditional percutaneous pinning techniques. (12) Intra-operative musculoskeletal sonography (IoP MSK- US) can further increase the safety of these interventions. (13)

I.1. Point of care ultrasound

In recent decades, emergency ultrasound (US) diagnostics have undergone enormous development. (14) Point of care ultrasound (PoCUS) is the application of US to make immediate patient-care decisions. (15) These procedures are performed by non-radiologists who seek answers to targeted clinical questions. (15) The advantages of various PoCUS examinations are now proven by high-level evidence. (16)
Musculoskeletal (MSK) PoCUS is a relatively new concept which has been enabled by the development of high-resolution sonography. (17)

I.2. Musculoskeletal sonography in children

The guiding principle of radiation safety is the concept of "ALARA" (as law as reasonably achievable). The practice of this principle is especially important in childhood as the growing body is more sensitive to radiation. (18) Examinations with ionisation exposure should be performed only in cases when there is no alternative diagnostic test and the results may have clinical consequences. Although standard two-plane X-rays of a joint do not involve significant ionisation, there are no definite "safe minimal doses". (19) The practice of emergency departments (ED) show great differences in X-ray application even in the case of simple injuries. (20) MSK -US can be a diagnostic imaging alternative to X-rays in various paediatric injuries. (21) To our present knowledge, MSK-US does not have any harmful effects on the tissues and can be repeated unlimitedly. (21) Additional advantages of US are the portability, relative low cost, lack of radiation and no known contraindications. (22)

Application of MSK-US is examiner dependent and it may be difficult to carry out standardised examinations. (23) Nonetheless, examining individual areas can be learned quickly and effectively by healthcare staff who do not have any special radiological training. (24)

MSK-US involves the use of high-frequency sound waves up to 24 Megahertz (MHz) to image soft tissues and bony structures in the body for diagnosing pathology or guiding real-time interventional procedures. By increasing the frequency, better resolution is achieved, so penetration decreases to a few centimetres. (25) Given that most musculoskeletal structures are superficial, they can be clearly visualised by US. This is particularly advantageous in the areas of the wrist and the elbow, where the bones are covered with a thin soft tissue (26)

I.3. Sonographic diagnostics of bone fractures

The principle of fracture sonography has been reported by Leitglieb in 1986. (27,28) The first Hungarian reports were presented by Farbaky and al. in 2004. (29) Over the last two decades many papers confirmed the role of US in the diagnostics of various bone fractures. US had been demonstrated as an effective method for the detection of fractures of the skull, fingers, forearm, elbow, hip and sternum. (30,31,32,33,34) It has also been used as a method for identifying stress injuries and occult fractures of the scaphoid bone, clavicle, rib, foot and ankle. (34,35,36,37,38,39,40) Sonography of long bone fractures also can be used as fast screening method in emergency departments to facilitate triage. (41) Further researches have confirmed the diagnostic benefits of US for fracture detection in battlefields and in health care facilities with limited sources. (42) In a systematic review and meta-analysis Schmid and al. found 91% sensitivity and 94% specificity of US fracture identification following acute trauma. (43) Other systematic reviews showed similar results. (11,22) The most accurate diagnostic matches between X-rays and sonography were shown at paediatric distal forearm, proximal humeral, elbow, ankle and long bone fractures. (11,22,43) In 2015 the European Federation for Societies of Ultrasound in Medicine and Biology (EFSUMB) issued a recommendation on the sonographic fracture investigation and its documentation of paediatric wrist, elbow and proximal humeral fractures. (44) Although there is a considerable evidence that the sensitivity and specificity of US are high, randomised trials for high level evidences are still missing. (45) Despite the generally excellent results, US fracture diagnostics has not become a widespread routine and most local diagnostic protocol do not include its use. There can be several reasons for this. Most of the studies were made by emergency departments and investigated relatively small number of cases. It is a further problem that US is examiner dependent and requires special training. A physician's basic ultrasonic training is evident in an ED, but they are less experienced in paediatric orthopaedic trauma. (46) On the contrary, orthopaedic surgeons who provide definitive care usually do not have ultrasound qualifications. (24,46)

I.4. Physical basics of fracture sonography

The cortex of the bone completely reflects ultrasound waves. The cortical line can be mapped by a linear transducer if it is held parallel or perpendicular to the longitudinal axis of a tubular bone. (29) With modern devices even, a tenth of a millimetre cortical gap can be detected. (25,29) Paediatric bone fractures (torus fractures, angulated greenstick fractures, epiphyseolysis) show a typical pattern. The degree of angulation can be measured with the same accuracy as shown in X-rays. A significant part of the paediatric joints is just partly ossified and consist mainly of cartilaginous tissue which is "invisible" to standard X-rays. (8) Chondral avulsions, apophyseal injuries which have a minimal ossification centre can also be visualised by sonography. (8) Fluid accumulation in the joints can be an indirect sign of occult fractures and it is easier to detect by US. (23,25,29)

I.5. Intraoperative musculoskeletal sonography

Intra- and postoperative application of high-resolution US in musculoskeletal trauma is a relatively new method for various purposes. MSK-US is advantageous in the visualisation of the relationship of various soft tissues (i.e. tendons, nerves, arteries) and implants which are undetectable by X-rays. It can also reduce the need of radiation. (29) Recently, several authors have reported positive experiences with US in different musculoskeletal operations. Lee and al. use US for intraoperative reduction of radial neck fractures. (47) Soldado and al. use sonography during medial pinning of paediatric supracondylar humeral fractures to avoid iatrogenic injury of the ulnar nerve. (48) Several papers confirmed the utility of peri- and postoperative use of sonography to detect dorsal cortical screw penetration after plate osteosynthesis of distal radial fractures. (49,50) In a cadaveric study Saengsin and al. found that the reduction of femoral shaft fractures can be monitored by US during minimal invasive plate osteosynthesis. (51) Zhe and al. described ultrasound-guided intramedullary nailing of femoral shaft fractures which reduces intraoperative radiation exposure. (52) Initial results of US guided carpal-tunnel releases are encouraging. (53)
Ventral and dorsal area of the wrist is easily accessible for producing a detailed sonographic image due to the proximity of the soft tissues to the skin. Considering that operative approaches of paediatric forearm and wrist fractures are usually performed in a minimally invasive percutaneous way, IOP- US may be useful in this area to avoid iatrogenic soft tissue injuries. (13)

I.6. Sonography of paediatric elbow fractures

Elbow trauma is a very common injury in childhood. Elbow fractures account for 5 to 10 % of all fractures in children. Accurate diagnosis of elbow injuries can be difficult in many aspects. A clinical suspect of paediatric elbow fracture is usually confirmed or excluded by standard two plane X-rays. (54) In children a large part of the elbow joint consists of cartilage. (54) Fractures which affect the cartilaginous part cannot be visualised directly by X-rays. (8,55) It is also a difficulty that the elbow in growing children has six ossification centres which appear sequentially from 2 years of age. Distinguishing fractures from normal anatomic findings needs a special experience in paediatric trauma imaging. (54) Improper adjustments of the elbow during X-rays may result further mistakes. Indications of X-rays and interpretation of the results may differ depending on the providing physician. (6,7) Occult fractures and other acute disorders can be misdiagnosed. (56) Radial condylar (RC)fractures are sometimes invisible on the first X-rays although they can have serious clinical consequences in the case of instability. (57) Recent years several studies confirmed the positive role of US in the diagnosis of paediatric elbow trauma. (57,58,59,60,61,62,63) Most of these papers examined the significance of the sonographic fat pad sign (FPS) in certain types of fractures. Some papers suggest using standard sonographic planes. (64,65) Despite the good and encouraging results no comprehensive, generally accepted method has been developed for daily clinical practice.

I.7. Sonography of pulled elbow injuries

The clinical entity known as „ pulled” or “nursemaid elbow” (PE) or „radial head subluxation” is one of the most common upper limb injuries in childhood under the age of 5 years. (66,67,68) PE is caused typically by a sudden axial traction although certain injuries are associated with other mechanisms (69) Most protocols do not recommend any diagnostic imaging for confirming the presence of PE, reduction manoeuvre can be carried out by the physical findings and typical anamnesis. (69) Usually the child holds his upper extremity in a pronated and extended position, refuses moving it and may complain of wrist and elbow pain. (69). In certain cases, the condition even can be diagnosed and treated remotely. (70) PE is a benign, age-specific injury, without further clinical consequences when correctly recognised and adequately treated. (65,66,67,68,69) The main problem of PE is the difficulty of differential diagnosis in a small percentage of cases. (71,72) Clinical history is not always clear, and according to certain studies, 1-5% of children can have elbow fractures or other pathology which can mimic the physical findings of PE. (73,74,75) This percentage can be even greater by first health providers who are not so experienced in paediatric musculoskeletal trauma. Mostly supracondylar humeral (SCH) fractures can cause similar physical findings. (75) Reduction attempts in these cases can cause further unnecessary pain and iatrogenic dislocation. Application of reduction manoeuvres in uncertain cases without musculoskeletal imaging depend on the health provider's clinical decision. The most accepted method for ruling out fractures is a standard two plane radiograph. There is no clear recommendation that in which cases X-rays should be indicated. Considering that X-rays do not show clear pathognomonic sign for PE, most authors suggest that radiographs should be taken only in the cases of suspected fractures. (75) Few papers suggest the use of US to confirm PE. These studies are controversial, and authors report different sonographic characteristics of PE. (76,77,78,79,80) To our knowledge, an objective and simple imaging method which can be used by a clinician has not been yet reported.

I.8. Sonographic diagnosis and treatment of paediatric distal forearm fractures

Distal forearm fractures are the most common skeletal injuries in children. (2,3,4) Based on publications from different places in the world, their number has been growing steadily over the last thirty years. (81) Although generally these fractures show excellent healing tendency and good functional results, there are very different trends both in diagnostics and treatment worldwide. (5,10) In recent years, many authors have confirmed that US is an effective tool in the diagnostics of these fractures. Paediatric distal forearm is one of the most intensively investigated area of US fracture diagnostics although most papers involved relatively small number of patients and were made by emergency physicians. (82,83,84,85,86,87,88,89) Authors agree that US is as effective as X-rays for screening out negative cases and diagnosing fractures without displacement. At the same time there is some controversy if angulated or severely displaced fractures can be detected only by US. Publications generally deal only with primary diagnostics. A few authors reported other applications like US guided reduction. (87,88,89)

Torus or buckle fractures are very stable metaphyseal injuries without the risk of displacement. (10,90) US shows similar effectivity as X-rays in the diagnosis of torus fractures. Torus fractures heal rapidly, there are enough evidence that a removable splint for three weeks is better than a rigid cast. There is no need for repeated X-rays because these injuries do not have any risk of late complications. (10,90) Minimally displaced fractures can be treated similarly as torus fractures. (10) Angulated fractures up to 15 degrees with preserved continuity of the periosteum and under the age of 10 at girls, and 12 at boys can be treated with a simple splint and without any intervention. There is no agreement on how often these injuries should be controlled. (91) Most patients are checked by X-rays one or two times more until evidence of bone healing, although US could be a viable alternative in the judgement of angular deformity.

Displaced fractures beyond the acceptable limit of angulation need intervention. Most of them can be treated by closed reduction and 4-6 weeks rigid casting. (10,92,93,94) The EFSUMB does not suggest US diagnostics in the case of a suspected displaced radius fracture because of the uncertain diagnostic accuracy. (44) There are no clear recommendations or high-level evidences for the treatment of severely displaced paediatric distal forearm fractures. (93,94) Distal and severely displaced paediatric metaphyseal radial fractures with total rupture of the periosteum are generally considered unstable. Some authors suggest surgery only after unsuccessful conservative treatment, while others indicate operative interventions in the cases of potentially unstable fractures. (95) Contrary to adulthood, there is no need for an anatomic reduction in a child's distal forearm fracture. (96) Many studies confirmed the remodelling capacity of distal radial fractures in children. Very young children can tolerate even up to 40-50 degrees of distal radial angulation without late consequences. At the same time, the precise limitations of remodelling capacity are unclear. Most authors agree that a residual angulation of 15-30 degrees under the age of 10 at girls, and 12 at boys would totally remodel with time. (10,95) Clinical judgement of greater deformities and older age groups is contradictory. Severely displaced and shortened distal fractures are usually candidates for operative interventions. These fractures are very deformed and unstable because of total periosteal rupture. Although theoretically even these fractures can heal and remodel by conservative treatment most authors choose operative intervention because total remodelling is uncertain and functional recovery takes a long time. (97)

The principles of surgery of paediatric distal forearm fractures have not changed in the past five decades. The gold-standard operative method is closed reduction and percutaneous pinning. Although the many variations of percutaneous pinning are simple and effective in unstable distal radial fractures, they can also have many potential complications and disadvantages. Kirschner wire related complications are well known; migration of the pins, superficial infections, damage of the growth plate, skin irritation, and insufficient biomechanical ability to maintain the reduction without casting. (97,98,99,100,101,102) This latter fact is the main drawback of this technique: in addition to the discomfort associated with operation, it is usually necessary to wear a long or short rigid cast at least for 4 to 6 weeks postoperatively.Fractures in the area of the diametaphyseal junction represent a special problem: they are usually located too distally to be treated by conventional ESIN-technique and too proximal for Kirschner wire fixation. Lieber et al used transepiphyseal pinning in these cases. (103) Although the chance of an iatrogenic physeal injury is very small, a physeal arrest and progressive deformity can be a potential complication of any trans-epiphyseal stabilisation. (104,105,106,107) Other authors suggest a specially prepended long, physeal sparing elastic nail to eliminate this problem. All these methods require postoperative rigid long arm cast immobilisation for 4 to 6 weeks. (108,109,110,111)

I.9. Complications of radial elastic stable intramedullary nailing

In the past three decades flexible intramedullary nailing of displaced and unstable forearm diaphyseal fractures has become the gold standard operative method in children. (112.113,114) ESIN technique of the radius can be carried out from two entry points. (115) These are the lateral (distal radial side proximally from physis) and the dorsal approaches (through Lister's tubercle). (112,113) (**Figure 1,2**) Both approaches have potential complications. Lateral entry point can cause a 2.9% rate of transient and 0.3% rate of permanent injury to the superficial branch of the radial nerve. Rarely a painful neuroma also can occur. (115) Dorsal approach can cause a 2.6% rate of extensor pollicis longus tendon (EPL) rupture. Due to the consequences of these complications, recent studies and the original description advocate using the lateral approach although considering biomechanical aspects, the dorsal technique is more advantageous in distal fractures. (115)

Figure 1. Anteroposterior X-rays of different radial approaches of ESIN techniques
A: dorsal entry nailing **B:** lateral entry nailing

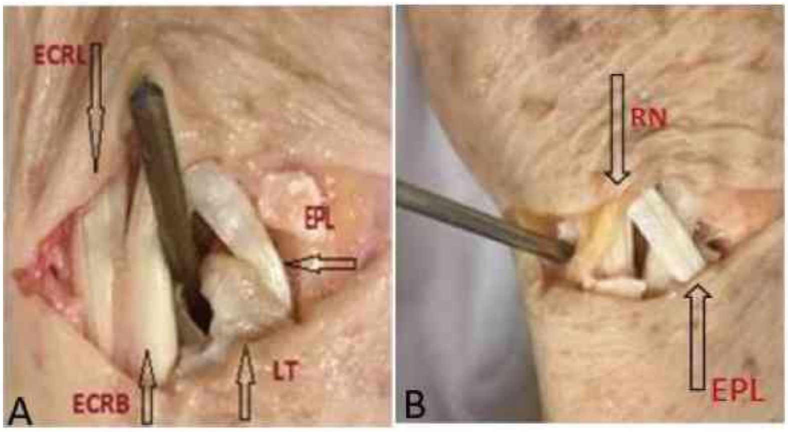

Figure 2. Relations of the elastic nail and the surrounding structures at the dorsal and at the lateral approaches (adult cadaver) **A:** Dorsal approaches (ERCL: extensor carpi radialis longus tendon, ECRB: extensor carpi radialis brevis tendon, EPL: extensor pollicis longus tendon, LT: lister's tubercle, **B:** Lateral approaches
EPL: extensor pollicis longus RN: radial nerve

II. Aims of the thesis

The aim was to prove the efficacy of a standardised five-point sonographic screening method of paediatric elbow fractures. US examinations were executed by orthopaedic surgeons in an emergency trauma centre.

In a prospective diagnostic study, we investigated a standardised two-points method in the differential diagnosis of paediatric pulled elbow. We developed an objective, point of care imaging method for confirming or ruling out PE.

We aimed to prove the diagnostic effectivity of ultrasound in distal paediatric forearm fractures in a prospective, two-centred study with large number of patients. Examinations were executed by orthopaedic and paediatric surgeons.

We also aimed to investigate the diagnostic difference of US in radial fractures with different clinical consequences.

We have developed a new operative method for severely displaced distal paediatric radial fractures. In our retrospective study we analysed the results of our technique, which is a stable, physis sparing osteosynthesis with a reduced period of necessary cast immobilisation.

We introduced a new ultrasound-assisted intraoperative aiming method for the ESIN technique of paediatric radius fractures. The aim of the procedure was to reduce the risk of EPL tendon injury during dorsal entry elastic nailing. This was an observational diagnostic study.

III. Patients and methods

III.1. Sonographic diagnosis of elbow fractures

Between January 2016 and August 2017 365 children (age 1-14) were enrolled in our study. Patients with isolated and closed elbow injury who needed standard two-plane elbow X-rays were included. We excluded children with open fractures and uncertain clinical symptoms when simultaneous indication of X-rays from other joints of the upper extremity were also needed. Point of care US was carried out as a part of the primary physical survey. US examinations were executed by a properly trained orthopaedic trauma resident and two orthopaedic surgeons. US pictures were made by high-frequency linear probes. (Zonare ZS3 Ultrasound System, Mindray®, L20-5W and L-14-5W linear array transducers)

We used a standardised protocol, which included five longitudinal sonographic planes: a dorsal one above the olecranon fossa (plane I.), lateral and medial views of the distal humeral consoles (plane II and III) a lateral view of the proximal radius (plane IV) and an image of the proximal ulnar surface. (plane V). (**Figure 3.**)

Pictures were saved for further analyses. The other unaffected elbow was also scanned so we had a comparable reference point at each plane. In plane I. above the olecranon fossa we sought the presence or absence of the elevated dorsal sonographic fat pad sign (eFPS) or lipohemarthros (LH) whereas the other longitudinal planes served to confirm any angulation or disruption of the bony cortex. (**Figure 4.,5.**)

Immediately afterwards we made two-plane X-rays from the affected side according to protocol. At children whose primary X-rays were negative and/or any of the US planes showed positive findings, radiography was repeated after 4 weeks of injury. The fracture was considered occult, if we detected callus formation. Images which have not met with standard requirements were excluded.US pictures and X-rays were analysed and compared by the clinicians and a radiologist. The radiologist was clinically blinded to any patient related information. Interrater agreements by Cohen's chance corrected kappa statistics of sonographic fat pad sign and cortical plane abnormalities were calculated between the examiners and the radiologist. We used GraphPad QuickCals® program to calculate the degree of agreement with Kappa.

We also estimated the rate of match of the presumed and final diagnosis. Presence of pathologic sonographic fat pad sign and the cortical abnormalities were evaluated separately and together. We used MEDCALC® diagnostic test evaluation calculator to determine the specificity, sensitivity, positive and negative predictive values. Clinical approval of our diagnostic study was permitted by our Institutional Medical Board. An informed consent was obtained from the parents of all patients.

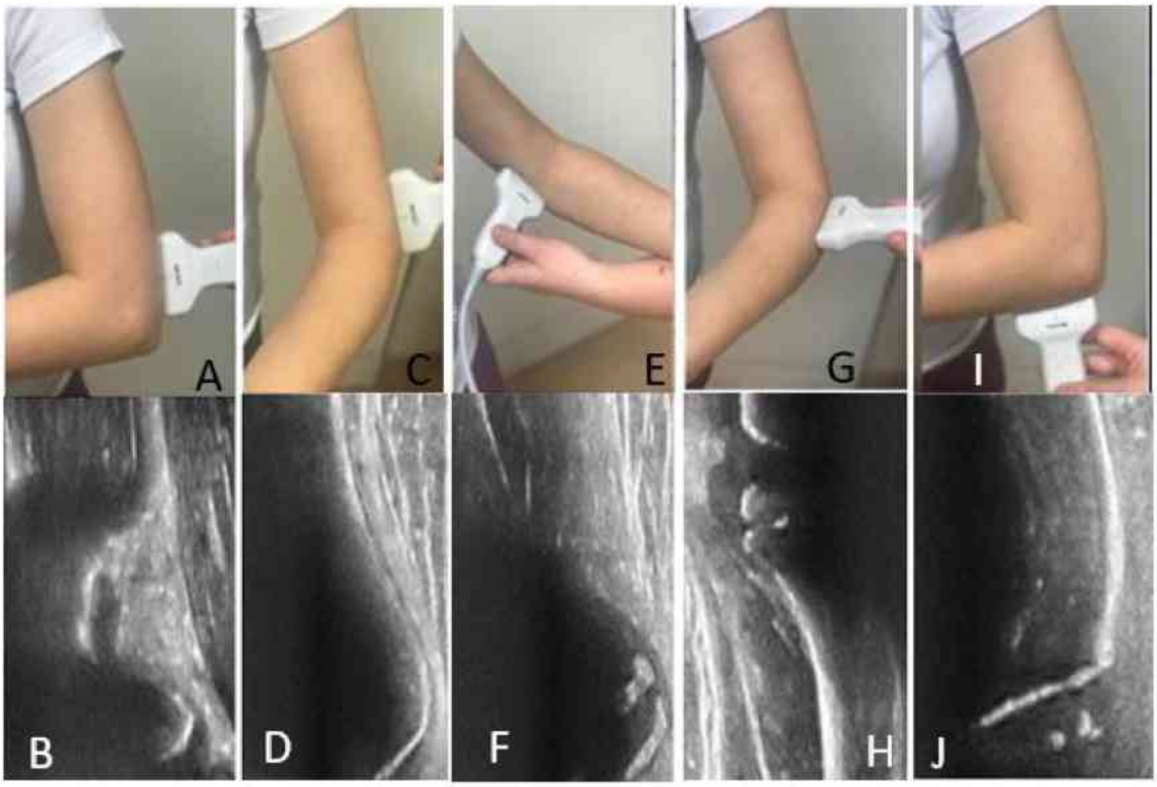

Figure 3.

Standard transducer positions and views of the five-point sonographic examination of elbow fracture in children.

A: plane I. transducer position. **B**: sonographic view of the olecranon fossa in plane I. **C**: plane II. transducer position. **D**: sonographic view of the lateral humeral condyle in plane II. **E:** plane III. transducer position. **F**: sonographic view of the medial humeral condyle in plane III. **G**: plane IV. transducer position **H:** sonographic view of the proximal radius in plane IV. **I**: plane V. transducer position**. J:** sonographic view of the olecranon in plane V.

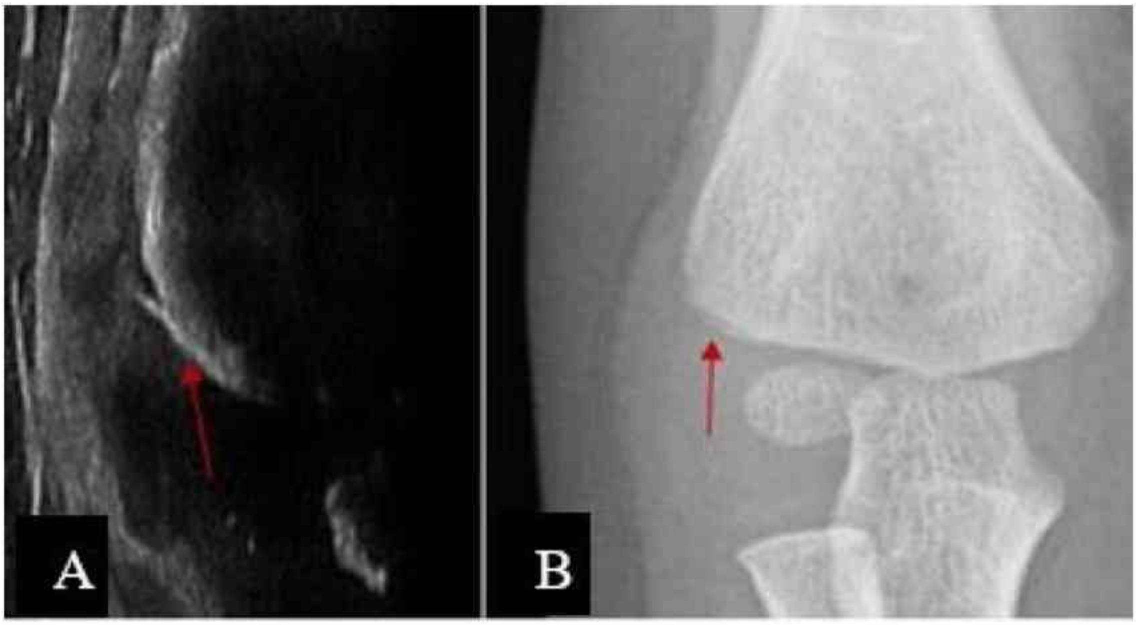

Figure 4. Anteroposterior X-ray and ultrasound picture of a radial condyle fracture in a 6 years old child. Signs of cortical disruption.

A: Cortical line disrupts in sonographic plane II. (arrow). **B:** A subtle cortical infraction can be seen on anteroposterior X-ray(arrow)

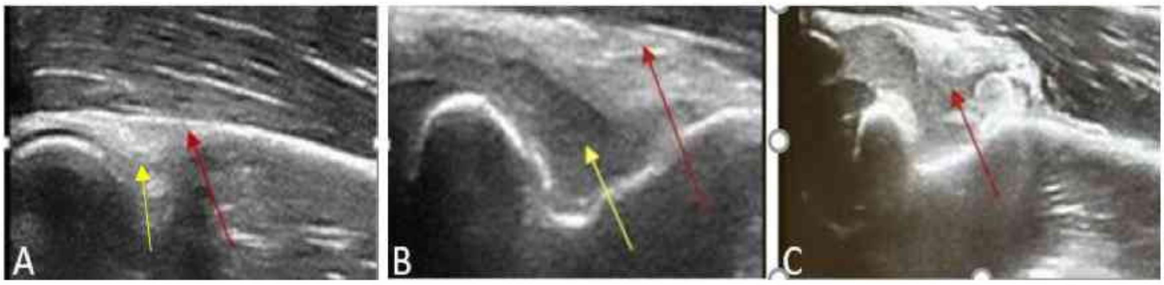

Figure 5. Sonographic signs of normal fat pad, elevated fat pad and lipohemarthros

A: Normal fat pad sign (yellow arrow) Border of the fat pad is at the level of the dorsal humeral cortical line (red arrow) **B:** Elevated fat pad sign -fat pad border exceeds humeral line (red arrow), fluid is distinguishable (yellow arrow) **C:** Lipohaemarthros - there is an inhomogeneous indistinguishable mass in the fossa (red arrow)

II.2. Sonographic diagnosis of pulled elbow

Between October 2016 and November 2017 205 children were examined with the clinical suspect of PE. (Mean age: 2.3 years). Inclusion criteria were the typical clinical signs of PE: painful, motionless, extended or slightly flexed and pronated arm following a traumatic event under the age of six. We excluded children older than six years and patients with pronounced elbow swelling and initially flexed and supinated upper arm position. A two-plane point of care US examination was carried out at each patient immediately after history taking and primary physical survey. Examinations were done by two orthopaedic surgeons, and a properly trained orthopaedic resident in training.
US pictures were made by high-frequency linear probes. (Zonare ZS3 Ultrasound System, Mindray®, L15-5W and L20-5W linear array transducers)
Imaging included a standard longitudinal central dorsal view over the olecranon fossa and a longitudinal ventral view over the radiocapitellar joint. **(Figure 6.)**
During examinations children lay on a bed, their arm was cautiously placed in an extended and pronated position for the ventral, and slightly flexed position for the dorsal view. We also examined the unaffected extremity to compare the results. Pictures were saved and the presence or absence of the dorsal sonographic elevated fat pad sign and the ventral intraarticular synovial fringe enlargement (SFE) were recorded. **(Figure 7.)**
Painless movement of the affected extremity within 15 minutes with or without a palpable click were considered as successful reduction manoeuvre and confirmation of the diagnosis. Patients with positive FPS and/or further pain and restriction of the movement were X-rayed and immobilised in an open plaster cast or brace. If symptoms have not ceased after 3-5 days, immobilisation time was prolonged and elbow X-rays were repeated in the 3rd week after injury. Fracture positivity on X-rays or callus formation on the 3rd week radiographs ruled out PE.
Sonographic pictures were saved and analysed by a radiologist who was blinded to any patient-related clinical information. Interrater agreements of eFPS and SFE were calculated between the radiologist and the clinicians. We used Cohen's chance corrected kappa for calculation. We used GraphPad QuickCals® program to calculate the degree of agreement with Kappa. We used MEDCALC® diagnostic test evaluation calculator to determine the specificity, sensitivity, positive and negative predictive

values of the two parameters both separately and together. We also estimated the rate of match of the presumed and final diagnosis.

Clinical approval of our diagnostic study was permitted by our Institutional Medical Board. An informed consent was obtained from the parents of all patients.

Figure 6. Transducer positions of two-point sonographic pulled elbow examinations
A: ventral longitudinal position above the radio capitellar joint **B:** dorsal longitudinal position above the olecranon fossa

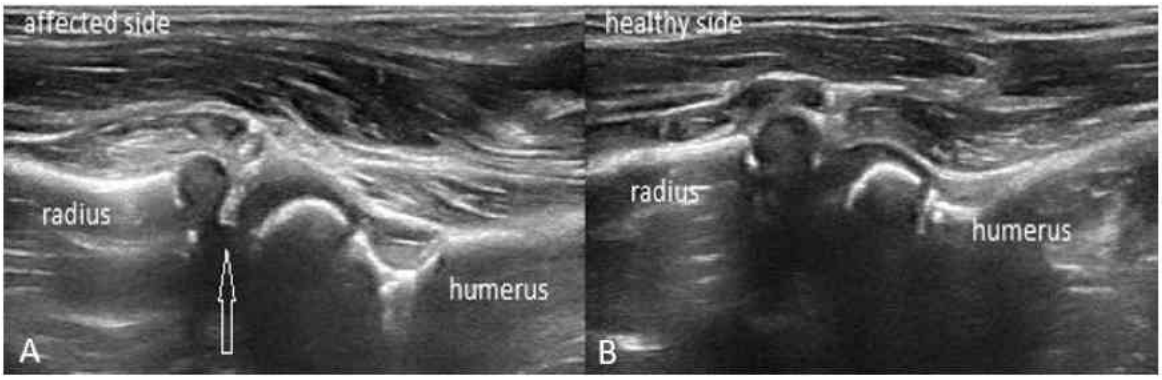

Figure 7. Ventral views of the sonographic two-point examination of pulled elbow. Synovial fringe enlargement.
A: A marked hyper-echoic structure in the radiocapitellar joint is the sign of synovial fringe enlargement. **B:** healthy side, no sign of interposed tissue.

III.3. Sonographic diagnosis of distal forearm fractures

Between December 2011 and December 2015 467 children (age 1-14) were enrolled in our study. Patients with isolated and closed distal forearm injury who needed standard two-plane wrist X-rays were included. We excluded children with open fractures and uncertain clinical symptoms when simultaneous indication of X-rays from other upper extremity joints were also needed.

Point of care US was carried out as a part of the primary physical survey. US examinations were executed by six properly trained doctors: two orthopaedic trauma residents, two orthopaedic surgeons, one paediatric surgeon, and one paediatric surgeon resident. We used a standardised protocol, which included six longitudinal sonographic planes: dorsal radial, dorsal ulnar, medial ulnar, lateral radial, ventral radial and ventral ulnar. (44) **(Figure 8.)**

Figure 8. Transducer positions and sonographic pictures of the six-point ultrasound examination of paediatric distal forearm fracture **A**: transducer position in dorsal ulnar plane **B:** dorsal ulnar sonographic view **C:** transducer position in medial ulnar plane **D:** medial ulnar sonographic view **E:** transducer position in ventral ulnar plane **F:** ventral ulnar sonographic view **G:** transducer position in ventral radial plane **H:**ventral radial sonographic view: **I:** transducer position in lateral radial plane **J:** lateral radial sonographic view **K:** transducer position in dorsal radial plane **L**: dorsal radial sonographic view

US pictures were made by high-frequency linear probes. (Zonare ZS3 Ultrasound System, Mindray®, L15-5W and L20-5W linear array transducers) Pictures were saved for further analyses. Immediately afterwards we made two plane X-rays from the affected side according to protocol. Images which have not met with standard requirements were excluded. US pictures and X-ray results were analysed and compared. We used MEDCALC® diagnostic test evaluation calculator to determine the specificity, sensitivity, positive and negative predictive values. Clinical approval of our diagnostic study was permitted by our Institutional Medical Board. An informed consent was obtained from the parents of all patients.

III.4. Elastic intramedullary nailing of distal radial fractures

We reviewed retrospectively 104 patients who underwent operations due to severely displaced distal forearm or diametaphyseal radial fractures between November 2012 and December 2017. 84 children were treated with short, prebent double elastic nails. 20 patients were treated by single titanium nails and a special end seal. (Depuy®, Synthes®, TEN®, End Cap ®) Indications for surgery included closed and unstable distal radius fractures with severe displacement and shortening. We excluded open fractures, physeal injuries, and pathological fractures. All procedures were performed under general anaesthesia and C-arm image intensifier control. A single-shot antibiotic prophylaxis was routinely used. All children were treated by six surgeons experienced both in the ESIN and percutaneous pinning technique. The parents were informed about other treatment options. A postoperative mobilisation program has begun in the first day and a short removable splint has been applied.

Standard two-plane X-ray images were made in the postoperative first, 4^{th}, 12^{th} and 24^{th} weeks. Angulation of the radial epiphysis was measured in coronal and sagittal planes. We considered reduction perfect if radial articular deviations were below 5 degrees both in anteroposterior and lateral planes. Residual angulation between 5 and 15 degrees was considered good. Angulations between 15 and 30 degrees were graded as acceptable under the age of 12 at boys and under the age of 10 at girls. Greater than 30 degrees of angulations or deviations out of the expected remodelling range in older children were considered as bad. Nails were removed at 6 to 36 weeks after the operation in general or in local anaesthesia.

Our method is a modification and special application of the conventional and existing ESIN technique. Clinical application of the technique has been accepted and permitted by our medical review board and by the Hungarian Paediatric Trauma Committee and by the Hungarian Paediatric Surgery Committee. Possible benefits, risks, and complications, along with other methods, were explained to all parents of each child, and an informed consent was obtained from them. Clinical approval of our retrospective study was permitted by our Institutional Medical Board.

III.4/1. Operative technique - short double intramedullary nailing

Patients are under general anaesthesia. The arm is in a pronated and extended position and placed on a fluoroscopically translucent table. The first step is closed reduction under image intensifier. If reduction cannot be achieved by single manual manipulation, a 2 to 3 mm diameter blunt ended Kirschner-wire (K-wire) or elastic nail is inserted to the fracture gap from a dorsal stab incision. Using the pin as a lever arm, the distal fragment is raised up and slid forward onto the proximal end. **(Figure 9.)**

After successful reduction, we determine the insertion points of the short elastic nails. The first point is the dorsal site of distal radius, the area of Lister tubercle, just proximal to the physeal line of the radius. After skin incision, we gently dissect the soft tissues, and we open the medullary canal with an awl. A "c"- shaped prebent short and relatively thick (8–12cm long and 2.5–3.5mm diameter) titanium elastic nail is inserted into the distal medullary canal of the radius. The nail is gently moved forward along its curvature until its distal end enters the medullary canal of the proximal fragment. A moderate pressing force is applied, and the nail tip becomes impacted. In this position, the convex side of the nail faces the fracture line of the anterior cortex when observing from a lateral view. If the position of the first nail is optimal, we determine the entry point for the second one. It is the distal radial site of the radius, just proximal to the growth plate.

The second nail is usually thinner (2–2.5mm in diameter) and prebent to a "c"-form shape. Similarly, to the technique described above, this nail is advanced forward along a radial-ulnar and distal to proximal curvature.

Figure 9. Percutaneous reduction of severely displaced distal paediatric forearm fracture

A: A blunt ended K-wire inserted into the fracture gap (intraoperative picture) **B-E**: using the K-wire as a lever arm, the distal end of the radius is replaced to the proximal fragment (Intraoperative X-rays by image intensifier) **F:** although the reduction is perfect, fixation is mandatory because the fracture is unstable

After reaching the medullary canal of the proximal fragment, the nail is pushed further with a controlled force, until tightness is achieved. Observing from an anteroposterior view, the convex side of the nail faces the ulnar cortex of the radius **(Figure 10.)** If the prebent curve of the short nail is not sufficient (the "c" shape is too flat), the end of the nail will get stuck in the ventral cortex. An overbent nail, however, cannot be inserted into the proximal medullary canal. In this situation, the nail is pulled back, and the degree of the curvature is corrected. By pushing forward a nail in a bad position, an additional iatrogenic ventral or dorsal cortical fracture can occur, so it is forbidden to use uncontrolled force during nail insertion.

Figure 10. Pre- and postoperative X-rays of distal paediatric forearm fracture treated by double elastic nailing

A: Anteroposterior and lateral X-rays of an unstable distal metaphyseal forearm fracture of a 9 years old child **B:** Radial fracture is stabilised by short, double elastic nailing. Ulnar fracture is also stabilised by conventional anterograde elastic nailing to increase stability.

III.4/2. Operative technique – short single elastic nailing with End Cap ®

The initial steps of the surgical technique are the same as in the double nailing. Operation should be carried out by using a pneumatic tourniquet for good visualisation and protection of the tendons during implant insertion. This requires approximately one and half cm wide transverse incision. The insertion point of the nail should be placed proximally to the physis in the dorsal midline or on the lateral side of the radius. It is not suggested introducing the implant through the Lister's tubercle because the end seal has a greater diameter than the elastic nail and in the case of bad positioning the EPL may be damaged. The prebent, short "c"-shaped elastic nail is inserted to the radius. Convexity of the nail faces anteriorly. After reduction and implant positioning, the end of the nail should be cut off to leave a free 0.5-1 cm long section out of the bone. End Cap® should be applied after clear visualisation and protraction of the surrounding tendons. End Cap® cannot press or touch the physeal plate. Skin is closed above the smooth end of the end seal. For stable fixation the threads of the seal should be attached to the bone. If the implant is very protruding or cause tension of the skin, it is suggested to remove it, and cut the nail shorter or push it deeper. After correction, the seal can be repositioned.

A conventional anterograde ulnar elastic nailing should be also carried out if there is a concurrent ulnar fracture. Ulnar nailing is suggested in both techniques. (114) Nailing of the ulna is suggested after radial stabilisation. **(Figure 11)**

Figure 11.

Elastic short intramedullary nailing with End Cap®

A: Severely displaced distal forearm fracture of a five years old child. Metaphyseal part of the fracture is very small. **B:** After reduction the medullary canal is opened just proximal to the physeal plate. **C-D:** A thick (3 mm diameter) prebent nail is inserted into the medullary canal. Position of the nail is controlled by lateral (C)and anterior (D) X-rays. **E-F:** Ulnar fracture is also stabilised by conventional anterograde nailing. End of the radial nail is sealed by the End Cap®. Reduction is checked by anterior (E) and lateral (F)X-rays.

III.4/3. Postoperative care

For the first 1 to 2 weeks a short, removable splint is applied. The purpose of the splint is mostly the postoperative pain relief. After the splint is removed, wrist and forearm movements with full range of motion can be started. Hard physical work, sport activity is recommended from the postoperative sixth week when X-rays confirm callus formation.

III.5. Intraoperative sonography of radial elastic stable intramedullary nailing

We performed cadaveric examinations on six human adults. EPL and Lister's tubercle was visualised by high frequency (20 Mhz) ultrasound imaging.
. (Zonare ZS3 Ultrasound System, Mindray®, L20-5W linear array transducer)
After sonographic determination of the insertion points, we positioned an elastic nail through Lister's tubercle according to standard dorsal technique. Position of the EPL relative to the elastic nail was examined from transverse and longitudinal planes. We bent the extraosseal end of the nail in a slight radial direction and cut beneath the skin in a maximally palmar-flexed wrist position. This was followed by preparation of the area and comparing the sonographic and anatomic findings.
Cadaveric dissections all correlated with ultrasonographic findings: distance of EPL and nail was median 0.5 cm (range: 4.4– 5.2cm) clinically, and 0.48cm (range: 0.44–0.5cm) measured in US. There was no tendon damage, obstruction or friction.
Following our cadaveric experience, we began using intraoperative ultrasound during elastic nailing of paediatric radial fractures.
A written informed consent was obtained from the parents of all patients. Between January 2015 and November 2016, 77 radial fractures were operated by dorsal entry elastic nailing under US guidance. Inclusion criteria were children with closed and displaced radial or forearm fractures which were candidates for operative ESIN technique. We excluded children with closed growth plates, open fractures and comminuted fractures which could not be stabilised by intramedullary nailing. Patients' age was between 4 and 15 years and had closed and displaced radial or forearm fractures with open growth plates.

We used aseptically isolated high frequency linear probes and sterile gel for the intraoperative technique. First, we determined the insertion point. After skin incision and soft tissue separation, we targeted the radial slope of Lister's tubercle with a sharp Kirschner wire. After we pressed the wire softly to the bone, we checked its position with image intensifier and IOP-US. Medullary canal opening with a sharp awl was also monitored by US and an elastic nail of 2 to 2.5mm diameter was inserted.

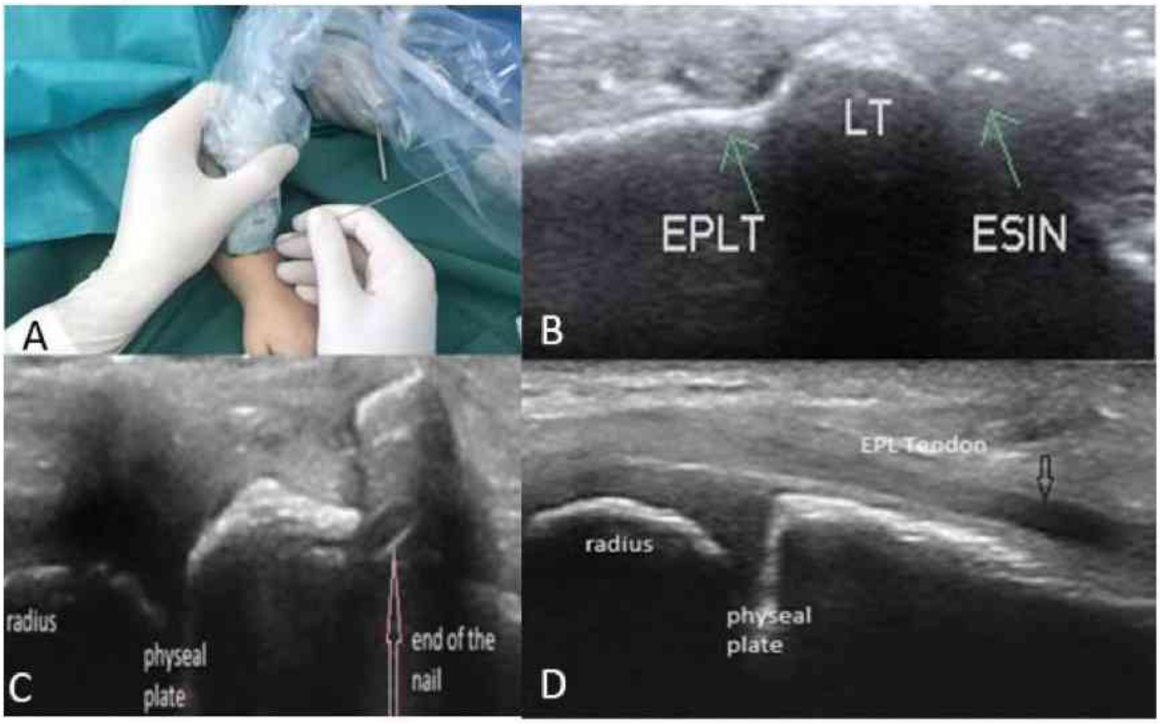

Figure 12. Sonography -assisted aiming of the radial side of Lister's tubercle and intraoperative ultrasound views of the dorsal entry elastic nailing of the radius
A: Lister's tubercle is aimed by a K-wire under sonographic checking. Transducer is aseptically isolated **B**: Transverse intraoperative sonographic view of the nail and tendon **C:** Longitudinal intraoperative sonographic view of the radius and the nail's extraosseal end. Tendon is not visualised in this plane. **D**: Longitudinal intraoperative sonographic view of the radius and the EPL tendon. (arrow) Nail is not visualised in this plane. EPL=extensor pollicis longus tendon, ESIN= elastic stable intramedullary nail, LT=Lister's tubercle

Operative technique and fracture reduction were made according to protocol. After cutting the end of the nail, we rechecked its position relatively to Lister's tubercle. EPL has been also checked in longitudinal and transverse plane, we analysed its relation to the extraosseal part of the nail. (**Figure12)** Continuity of the tendon has been checked by dynamic examination while passively flexing and extending the wrist and the thumb. In patients where we found that the nail was too close to the tendon or the EPL got stock during dynamic assessment), we corrected its position. Procedures were executed by 2 orthopaedic surgeons experienced in ESIN technique and with musculoskeletal US qualifications.

IV. Results

IV.1. Sonographic diagnosis of elbow fractures

Out of the 365 children we identified 165 positive findings (45, 2%) by primary X-rays.

We found 29 (17.5%) radial condylar, 84(50.9%) supracondylar humeral, 19 (11.5%) proximal radial, 7 (4.2%) proximal ulnar, 14 (8.4%) medial epicondylar fractures, 3 (1.8%) fractures with joint dislocations, 2 (1.2%) joint dislocations without fractures, and 7 (4.2%) fracture combinations which affected two or more bones. We did not find injuries among these patients that we could not categorised into one of these groups.

All fractures or dislocations had at least one positive finding out of the five planes.

112 fractures showed positivity in at least two planes.

Out of the fracture combinations 6 showed cortical abnormality in two, one in three planes. Sonographic FPS was negative in one radial condylar, two proximal radial and two medial epicondylar fractures. All these fractures showed positivity in at least one other longitudinal plane.

There was no sign of cortical abnormality in plane II.-V. at 3 medial epicondylar, at 24 supracondylar fractures and at the elbow dislocations. All these injuries showed eFPS or LH in ultrasound.

All radial condylar, proximal radial and proximal ulnar fractures showed at least one positive finding in plane II.-V.

12 children had sonographic FPS positivity without X-ray abnormality**.** Out of these patients 7 had a marked LH positivity, and 5 children showed mildly elevated FPS in

US. The LH positive elbows all showed callus formation on follow-up X-rays. These injuries were considered as occult fractures.

The other five patients with mildly elevated FPS have not showed callus formation and were considered as elbow contusions.

7 other children with primary negative X-rays had cortical abnormality in one of the II-V planes without positive FPS. These patients have not showed abnormality on follow up X-rays.

Summing up a total of twelve pseudo-positives findings were identified. No pseudo-negativity was detected using the five examining points.

Evaluating the sonographic dorsal FPS as a sole parameter for fracture detection we found sensitivity: 0, 97, specificity: 0, 97, positive predictive value: 0, 97, negative predictive value: 0, 97.

Evaluating the effectivity of the II.-V. planes we calculated sensitivity 0, 85 specificity 0.96 positive predictive value: 0. 95, negative predictive value 0.87.

The overall values of the five planes were the following: specificity0.97 sensitivity 1, positive predictive value 0.97 negative predictive value: 1

Interrater agreements on the cortical plane abnormality were considered good and very good. (Kappa= 0.79, 0, 81, 0, 79) Agreements on differentiation of eFPS, normal FPS or LH in sonographic pictures were very good in all cases. (Kappa= 0, 83, 0, 86, 0, 82) Although we have not observed any pseudo-negative findings, the exact identification of the type of the injury only by US was possible in 113 cases. (68%) **(Table I.-III.)**

	Cortical plane abnormality	FPS
Examiner I. and radiologist	0.76	0.93
Examiner II. and radiologist	0.74	1
Examiner III and radiologist	0.79	0.93

Table I. Interrater agreements of sonographic abnormalities in the five-point elbow fracture ultrasound diagnostics (Kappa values: 0.81-1: very good, 0.61-0.80: good,0.41-0.60 moderate,0.21-0.40 fair, 0-0.20

N = 177 True positive = 165 pseudo-positive = 12 pseudo-negative=0	**Positive in Plane I.** Dorsal elevated fat pad sign (EFPS) / lipohemarthros(LH)	**Positive in Plane II.** Distal lateral humeral column	**Positive in Plane III.** Distal medial humeral column.	**Positive in Plane IV.** Proximal radial plane	**Positive in Plane V.** Proximal ulnar plane
Supracondylar humeral fractures n = 84	84 EFPS=6 LH=78	37	28	0	0
Radial condylar fractures n= 29	28 EFPS=6 LH=22	29	0	0	0
Proximal radial fractures n = 19	17 EFPS=14 LH=3	0	0	19	0
Proximal ulnar fractures n= 7	7 EFPS=7 LH=0	0	0	0	7
Fractures with dislocations n = 3	3 LH=3 EFPS=0	0	2	2	1
Medial epicondylar fractures n = 14	11 EFPS=8 LH=3	0	11	0	0
Dislocations n = 2	2 EFPS=0 LH=2	0	0	0	0
Fracture combinations n = 7	7 EFPS=0 LH=7	2	2	7	7
Pseudo-positive cases n = 12	5 EFPS=5 LH=0	5	2	0	0

Table II. Number of detected abnormalities of different elbow fractures in individual sonography planes LH: lipohemarthrosis eFPS: elevated fat pad sign

	Sonographic FPS	Cortical abnormality	Sonographic FPS+cortical abnormality
Sensitivity	96.49%	85.05%	100%
Specificity	97.56%	96.62%	97.56%
Positive predictive value	97.06%	95.93%	97.06%
Negative predictive value	97.09%	87.34%	100%
Positive likelihood ratio	39.56	25.15	41.00
Negative likelihood ratio	0.04	0.15	0.00
Accuracy	97.07%	91.02%	98.65%

Table III. Diagnostic values of the sonographic fat pad sign and cortical plane abnormalities of the paediatric five-point elbow fracture ultrasound

IV.2. Sonographic diagnosis of pulled elbow

Out of the 205 children 196 (95,6%) proved to have pulled elbow and 9 (4.39%) fractures. These latter injuries were type I. supracondylar humerus fractures by Gartland classification.

Sonographic SFE sign was identifiable in 156(76%) cases. eFPS was negative in all but one PE cases.7 children (3.41%) had type I.SCH fractures which were visible in the first X-rays, and two children had occult fractures, (0.97%) which were proved by the evidence of callus formation on the follow-up X-rays. These children all had positive FPS and negative findings for SFE sign.

Interrater agreement between the examiners and the radiologist showed good results in the evaluation of SFE, (0,76,0,74,0,79) whereas excellent (0.939,1,0.939) in the interpretation of FPS.SFE showed 83% sensitivity and 100% specificity, 100% positive predictive value and 18% negative predictive for PE as a sole parameter. Presence of the FPS proved to result 99% sensitivity and 100 % specificity,100% positive predictive value and 90 %

negative predictive value. Evaluating the two parameters together both sensitivity, specificity, NPV and PPV were 100%. **(Table IV-VI.)**

n=205	**Pulled elbow** (n = 196)	**Fractures** (n = 9)
Synovial fringe positivity	156	0
Sonographic fat pad sign positivity	1	9
Sonographic fat pad positivity and synovial fringe negativity	0	9
sonographic fat pad negativity and synovial fringe negativity	40	0
Sonographic fat pad and synovial fringe positivity	1	0
Sonographic fat pad negativity and synovial fringe positivity	155	0

Table IV. Sonographic findings of pulled elbows and supracondylar humeral fractures

	Sonographic eFPS	Synovial fringe enlargement	Sonographic FPS+positive SFE
Sensitivity	99.49%	83.05%	100%
Specificity	100%	100%	100%
Positive predictive value	100%	100%	100%
Negative predictive value	90.00%	18.37%	100%
Positive likelihood ratio	-	-	-
Negative likelihood ratio	0.01	0.17	0.00
Accuracy	99.51%	83.67%	100%

Table V. Diagnostic values of the two-plane sonographic method of pulled elbow

SFE: synovial fringe enlargement, eFPS: elevated fat pad sig

	SFE	eFPS
Examiner I. and radiologist	0.76	0.93
Examiner II. and radiologist	0.74	1
Examiner III and radiologist	0.79	0.93

Table VI. Interrater agreement of the evaluation synovial fringe enlargement (SFE)and sonographic elevated fat pad sign. (eFPS)
(Kappa values: 0.81-1: very good, 0.61-0.80: good,0.41-0.60 moderate,0.21-0.40 fair, 0-0.20 poor)

IV. 3. Sonographic diagnosis of distal forearm fractures

Out of 467 children we found 270 (57.8%) positive and 197(42.2%) negative results for distal forearm fracture. Sonography has shown 263 positive and 204 negative results. The fractures were divided into three groups based on clinical significance.

Children without the need of further clinical intervention were divided into group I. Injuries which needed only reduction manoeuvre were divided into group II. Unstable severely displaced fractures which needed operative intervention were divided into group III.

We also investigated the distribution of pseudo-negative and pseudo-positive cases in each group.

We considered the results pseudo-negative when sonography has not confirmed the presence of any fractures which were detectable on X-rays. All these results (n=7) were found in group I. Fractures which have been confirmed only by ultrasound were considered as pseudo-positive. Such results (n=7) were found also only in the group I. (Table VII.)

Based on our results we found sensitivity 0.97 and specificity 0.96 for sonographic fracture detection in the area of distal paediatric forearm. **(Table VII-VIII.)**

Distribution of fractures by significance (n = 270)	Positive on X-ray	Pseudo-negative on US	Pseudo-positive on US
Group I. Fractures without the need intervention (epiphyseolysis or torus fractures without displacement)	n = 188 (70%)	n = 7	n = 7
Group II. Fractures with angulation or moderate displacement which need reduction	n = 52 (20%)	n = 0	n = 0
Group III. Fractures with severe displacement which need operative intervention	n = 30 (11%)	n = 0	n = 0

Table VII. Distribution of pseudo -negative and pseudo-positive cases in the three groups of patients examined by distal forearm fracture sonography

Distal forearm fracture ultrasound in children	n=467
Sensitivity	**97.47%**
Specificity	96,56%
Positive predictive value	97.47%
Negative predictive value	96.57%
Negative likelihood ratio	0.03
Positive likelihood ratio	28.41
Accuracy	97.09%

Table VIII. Diagnostic values of paediatric distal forearm fracture ultrasound

IV.4. Short elastic intra-medullary nailing of distal forearm fractures

None of the 104 cases required reoperation. Implant migration did not occur. No deep septic complication was observed.

We detected a superficial skin infection at 3 children in the double nailed group. Inflammatory signs have disappeared after the nails had been removed. All fractures have been stably consolidated at the time of nail removal.

9 children had moderate skin irritation caused by the ends of the implants. After removing the nails these symptoms completely disappeared. No skin irritation was observed in children who had end seal protection.

No tendon or nerve injury was found in any of the groups. All but one of the implants were removed between the sixth and twenty-fourth postoperative weeks. In one patient one of the nails had been placed too deep (below the level of the cortical bone) so we could not remove it. The average follow-up time was 9 months to 4 years. Each child has healed with full function, no growth disturbance or movement limitation have developed.

Brace treatment required an average of 12 days. (1-4 weeks)

Analysing the X-rays made at the checking times the following results were obtained: In the group whose members were treated by double nailing, anatomic reduction was found in 70 children, good in 13 children and acceptable in 1 child. Out of 20 patients treated by single elastic nail and End Cap® 13 showed anatomic and 7 good reductions.

X-rays on the fourth postoperative week showed slightly worse results in the double nailed group: classification was changed from anatomic to good in 4 children, from good to acceptable in three children and 1child has been graded to bad category due to moderate secondary displacement. Children with single nail end End Cap® synthesis have not showed any tendency to secondary displacement. **(Table IX-X.)**

X-rays made in the 24th postoperative weeks showed anatomic reduction in all but one patient. This latter child showed good (12 degrees of dorsal angulation) reduction after one year, and anatomic reduction after 24 months.

Complications	**Short double elastic nailing** (n = 84)	**Short elastic nailing with End-Cap ®** (n = 16)
Skin irritation	9	0
Secondary displacement	1	0
Superficial infection	3	1
Deep infection	0	0
Nerve or tendon damage	0	0

Table IX.

Numbers of different complications in the two types of short elastic nailing techniques

Degree of axial deviation	Short double elastic nailing (n=84)			Mono-elastic nailing with end cap (N = 16)		
	1sth week	4th week	24th week	1sth week	4th week	24th week
Excellent (maximum 5 degrees of axial deviation)	70	66	83	13	13	16
Good (maximum 15 degrees of axial deviation)	13	17	1	3	3	0
Acceptable (maximum 30 degrees of axial deviation within remodelling range	1	0	0	0	0	0
Bad (axial deviation is out of remodelling range	0	1	0	0	0	0

Table X.

Degrees of axial deviations on X-rays after short elastic nailing of paediatric distal radial fractures at different checking times

IV.5. Intraoperative sonography of radial elastic stable intramedullary nailing

Ultrasonographic identification of EPL and Lister's tubercle in the transverse view was possible in all children. Determination of the position of the nail to EPL was also possible in all patients. Measured mean distance of the transverse view centre of the EPL and nail was 0.49cm by US. (range: 0.3–0.62cm, SD=0.66).Longitudinal view of EPL was not clearly defined in 2 cases.Based on the sonographic transverse view (insertion points were too close (< 0.3cm) to EPL) the operator decided repositioning the nails by 2 patients.On one occasion EPL movement was not seen with dynamic assessment, although the tendon was clearly identifiable. In this case, we decided re-bending the end of the nail. After correction, we were able to identify normal tendon movement. Sonographic procedures took average 5 minutes (range: 2–8 min. mean=4.8min) extra time during operations. We have not found EPL injury or septic complications postoperatively. All patients were followed for at least 12 months after operation. Nails were removed from all children without further complications.

V. Discussion

V.1. Sonographic diagnosis of elbow fractures

Most of the papers evaluating the utility of US in different elbow injuries concentrated on the presence of the sonographic FPS as a strong predictor of fractures. (58,59,60,61,62)
A positive radiological FPS develops when normal fat pad around the elbow is pathologically forced out from its resting place. (118)
Radiological FPS is a well-known phenomenon known for decades, many studies deal with its diagnostic value. (119,120,121,122,123) While appearance of anterior FPS in lateral X-rays can be normal, posterior is generally considered pathological. (121)
Distinction of normal and pathological radiological FPS is not clearly defined. Its presence related to fractures is controversial. Sonographic FPS seems much more specific than radiologic and differs from it. (125) While lateral radiographs in elbow flexion has a positive fat pad sign with 5 to 10 ml of fluid in the joint, sonography allows identification of 1 to 3 ml posteriorly. (125) Nomenclature of abnormal FPS or lipohemarthros is not unified in the literature. (126) We considered sonographic FPS elevated if the dorsal border of the fat pad moderately exceeded (2 -5mm) the level of the proximal humeral line in the dorsal longitudinal plane, and the border of the original fat pad and the fluid were clearly distinguishable. The diagnosis of LH was established if the border of the fat pad and intraarticular fluid were blurry, or the two seemed as an inhomogeneous, indistinguishable mass in the fossa and the elevation exceeded 5 mm.
In our series we have not observed interrater disagreement in assessing the type of the different sonographic FPS. Distinction of LH and eFPS may have some importance for detecting a bony injury. We found LH to be more characteristic in supracondylar humeral

and radial condylar fractures. The seven occult fractures with negative primary X-rays but positive sonography all showed LH.

We suppose that LH is rather a sign of occult fracture while post-traumatic elevated fat pad without any radiological abnormality can be the result of intraarticular fluid collection caused by a stronger impact. Several studies concluded that presence of radiological or sonographic FPS does not necessarily mean an occult fracture, but differentiation of LH and eFPS was not done. This however does not mean serious clinical importance because treatment and outcome of most paediatric occult elbow fractures and stronger joint contusions does not differ.

Unambiguously with other studies we think that the absence of abnormal FPS means the real importance which has a strong negative predictive value. (119,120,121)

In our series we found five children (1 radial condylar and two radial neck and two medial epicondylar fractures) with initially negative sonographic FPS.This can be since certain fractures do not cause immediate intraarticular bleeding or fluid collection. The elapsed time from the injury can also play a role in elevated fat pad or LH formation. Repeated US on the first week showed that FPS became positive in all fractures. At the same time cortical disruption and angulation were visible in the second (radial condylar fracture) or third (medial epicondylar fractures) sonographic planes so the presence of these fractures would not have been missed.

Utility of the II-V. longitudinal planes is due to the phenomena that ultrasonic waves are reflected totally by the bony cortex.

If the probe is parallel to the bone, the cortical side is represented as a sharp, straight line, and interruptions or angulations will be clearly visible. We have seen seven pseudo-positive cases when abnormality was present in the II and III planes. Out of these 6 were in the plane II and one in the plane III. No callus formation or other abnormality were confirmed at these children and complains disappeared at the latest in two weeks. Small disruptions were observed in the osteochondral line in these cases, which we think anatomic variations or small infractions without clinical consequences.

Radial condylar, proximal radial and proximal ulnar fractures all showed positivity in the corresponding planes thus these injuries can be detected even without the FPS.

Abnormality in the plane II-III. was less specific in medial epicondylar and supracondylar fractures, especially if these injuries are without displacement. X-rays of these fractures show very subtle findings. **(Figure 13.)** Several fractures with less clinical significance have not showed any cortical abnormality by US, but all showed FPS positivity so wold not have been missed. Elbow joint displacements without fractures also showed only LH positivity without another plane abnormality. In these cases, technically it was very difficult to visualise the standard planes, because of the altered joint relations. The degree of LH was enormous. Displaced fractures with operative indication all showed positive LH and at least one additional plane positivity.

In two young children (8 and 7 years old) we have found very subtle or no abnormalities in X-rays, and US raised the suspect of a fracture requiring operative treatment. In these cases (a proximal radial and medial epicondylar fracture) most of the broken parts consisted of cartilaginous tissue which is invisible to conventional X-rays. We assume that in younger children US sometimes can give more accurate informations about the exact nature of the fracture than X-rays. In such cases, an MRI scan may determine the issue of the surgical indication. **(Figure14,15.)**

A longitudinal anterior sonographic plane could also be very useful but taking account the pain caused by the extension of the arm in the presence of a fracture we did not take it as a routine part of our protocol.

The four cortical sonographic planes without plane I. showed abnormality in 87% in all fractures. Evaluating the cortical views and the FPS together the specificity increased to 0, 99 and sensitivity to 1, so using the five planes in a 90-degree bent position of the elbow seems to be enough.

Exact identification of the fracture types was possible in 68%. These were minimally or not displaced radial condylar, type I supracondylar, proximal radial and ulnar fractures.

Summarising our result, we conclude that US is an effective tool in the screening of paediatric elbow fractures. Using additional longitudinal planes is more effective than the evaluation of the sonographic fat pad sign as a sole parameter. US may be enough as a definitive diagnostic tool in negative cases. US is a very useful imaging modality to detect occult fractures, and bony injuries without displacements, and in certain cases could be used instead of X-rays.

Identification of the presence of fracture displacement or dislocation is also possible by US but exact determination of the type of clinically serious injuries is not possible without X-rays.

Figure 13. Supracondylar humeral fracture without displacement

A: Small cortical disruption can be seen in sonographic plane II (arrow) **B:** Cortical line does not show disruption in the contralateral healthy side. **C**: Lipohaemarthrosis in plane I. is a certain sign of a fracture. (arrow) **D:** Appearance of fat pad is normal in the contralateral healthy side. (arrow) **E:** lateral X-ray show radiological anterior fat pad sign (white arrow) and small cortical disruption in the ventral supracondylar area (red arrow). **F:** anteroposterior X-ray does not show any abnormality.

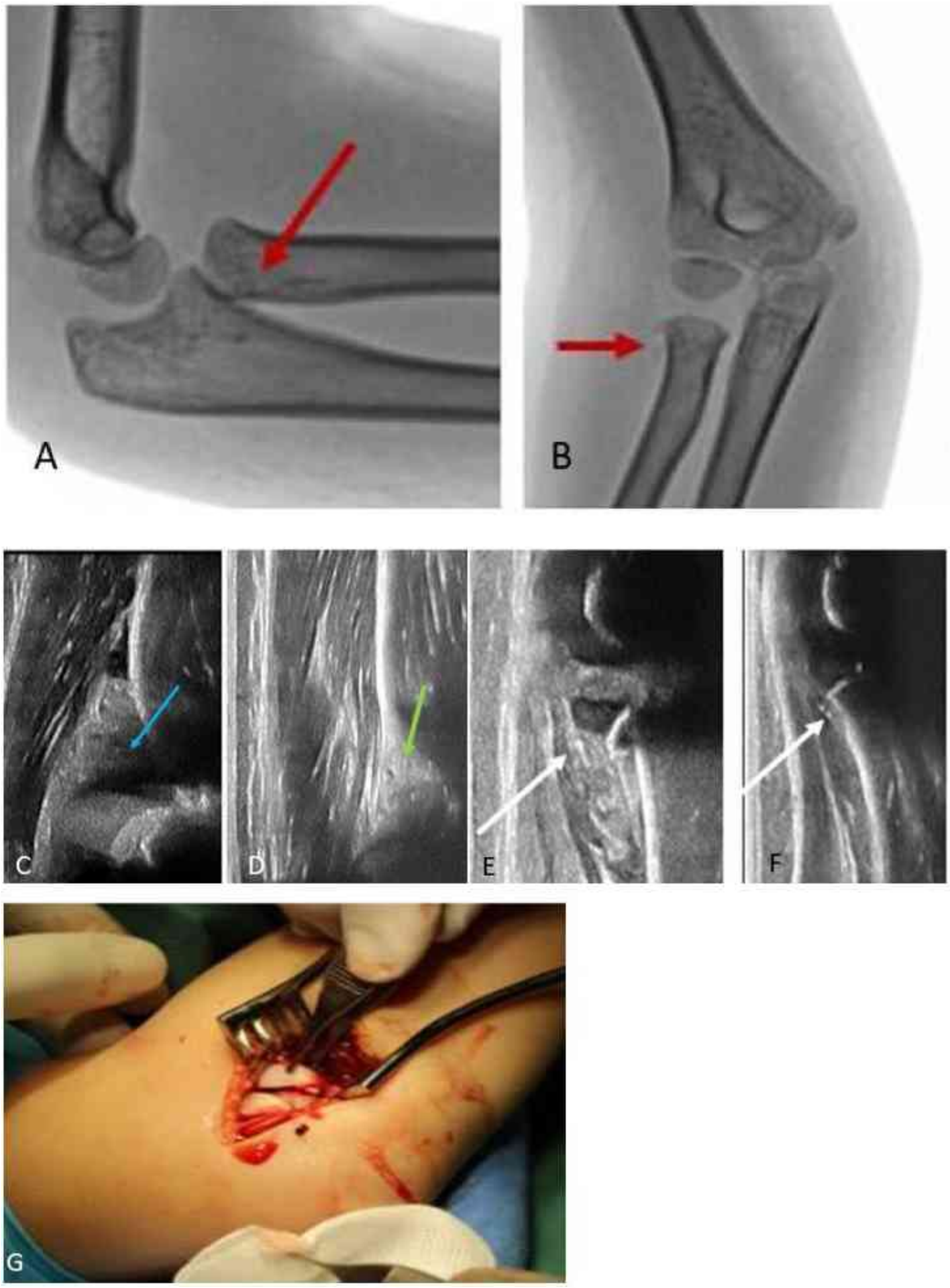

Figure 14. Intraarticular radial head fracture with subtle X-ray findings

A-B: lateral and anteroposterior X-rays of an elbow of a 9 years old child. Most of the radial head consists of chondral tissue, severity of fracture cannot be judged by X-rays (red arrows). **C**: Extreme lipoheamarthrosis of the affected side raise the suspect of a displaced fracture (blue arrow). **D**: contralateral side, normal sonographic fat pad (green arrow) **E:** US shows angulation of the radial head. Only half of the chondral head is visible(arrow) F: contralateral healthy side, sonographic appearance of radial head is normal **G**: Intraoperative picture: there is a displaced intraarticular radial fracture, which needs synthesis

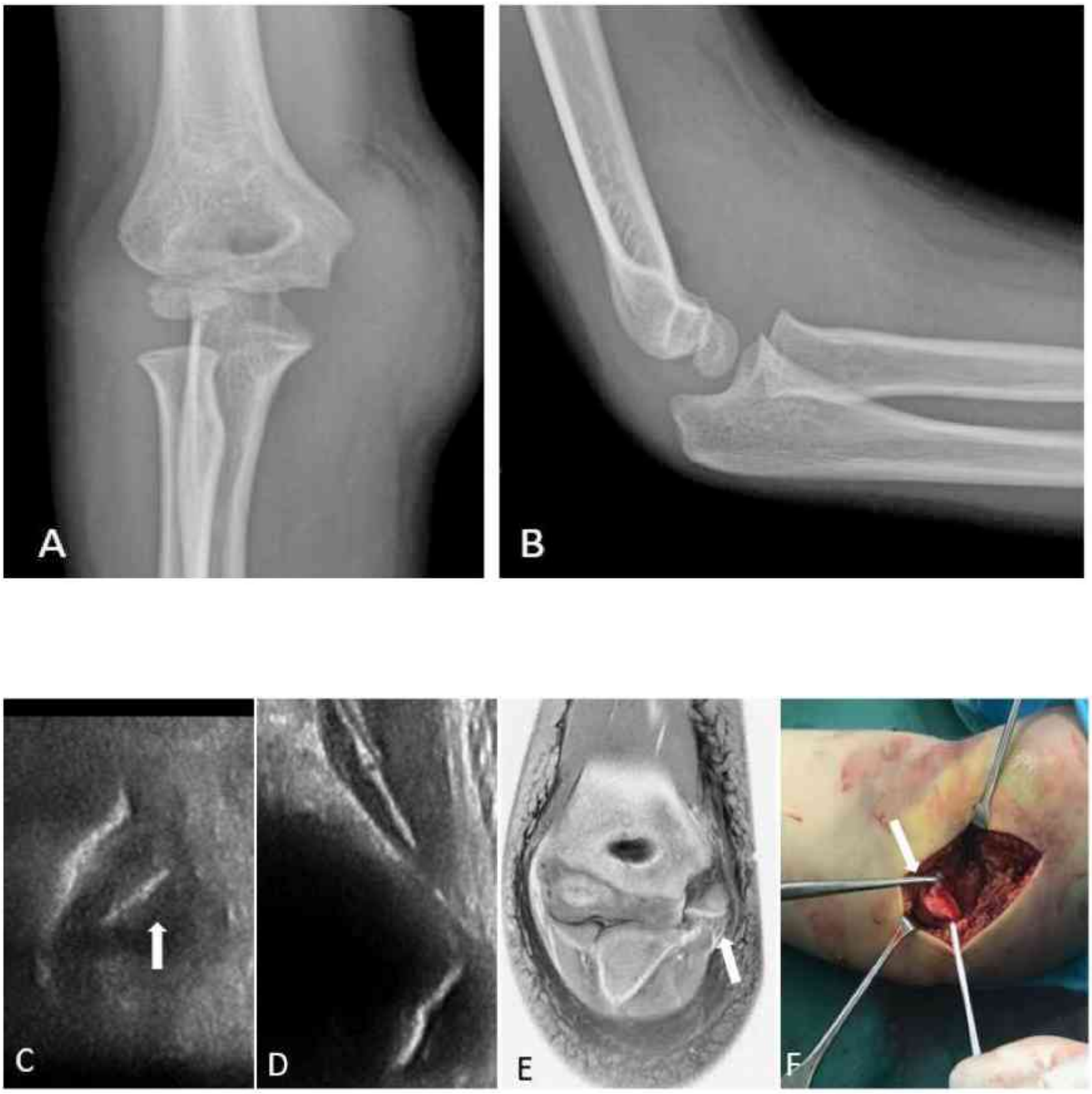

Figure 15. Displaced medial epicondylar fracture without X-ray abnormality

A-B: Anteroposterior and lateral X-rays of the elbow of an 8 years old child. There is a medial soft tissue swelling but no bony abnormality can be seen. **C:** sonographic view of the plane III, of the affected side – the hyperechogenic line indicates a dislocated medial epicondyle (arrow). **D:** unaffected side – there is no sign of avulsion. **E:** MRI scan of the elbow- arrow shows the avulsed epicondyle. **F:** intraoperative photo of the dislocated fragment

V.2. Sonographic diagnosis of pulled elbow

Exact pathological basis of nursemaid elbow is not clearly defined. At last 13 theories of the pathophysiology were described. Based on the current available evidence PE means a soft tissue interposition in the radiocapitellar joint. (75) The older nomenclature „radial head subluxation" suggest a well definable pathoanatomical abnormality but imaging modalities have not confirmed the presence of any joint incongruence. (76,77) Although several studies describe some special radiological sign which may relate to PE, these subtle changes have not proved useful in daily clinical practice. (128,129,130) Several papers reported encouraging results of sonographic diagnosis of PE. Radiocapitellar distance differences, annular ligament integrity and entrapment, changes in the shape of supinator muscle and enlargement of the synovial fringe were described as potential signs of PE. (127) Although ultrasound is cheap, fast and radiation-free imaging modality, the specific sonographic signs of PE described by various authors are controversial. (78,127,131)
These methods aimed to confirm the diagnosis of PE and operators have not used dorsal sonographic planes to detect potential fractures. With our combined two-point sonographic planes we searched signs which confirm or rule out both PE and fractures. According to several studies the most reliable and reproducible sonographic sign of PE is the presence of synovial fringe enlargement. (SFE) This phenomenon is also called „ hook" or „J" sign and suggests a soft tissue interposition in the joint. (78,79) Success of the reduction can be checked by its disappearance. Although certain authors found a 100% sensitivity and specificity for PE of this finding, others reported less excellent results. In our series we found only 76 % positivity of SFE at our PE cases. (25,78,127) It was a further problem that evaluation of the ventral plane was more dependent on the operators, interrater agreement showed less accuracy in this view. This can be due the fact, that US examination is less feasible in the ventral position, when the transducer should be held in a longitudinal position over the radiocapitellar joint while the child's elbow is extended and motionless. Normal parameters of the synovial fringe are not clearly defined, so enlargement can be evaluated by comparing the opposite elbow. (25) We found that a marked synovial fringe sometimes also can be seen in the healthy arm in children with generalized hyperlaxity, so determination of positivity is not possible in these cases. In spite of these we found SFE detection very useful, because the diagnosis of PE was made clear in more than two-thirds

of cases, and fractures never showed this change. Dorsal sonographic view improved this diagnostic accuracy.

Dorsal sonographic view proved easier to produce, and interrater agreement of evaluation the presence or absence of EFPS have been excellent in all cases. PE usually does not show fat pad abnormality which is a sign of intraarticular fluid accumulation caused rather by fractures or forceful contusions. Sonographic fat pad sign is more sensitive than radiological, even 1-3ml intraarticular fluid accumulation can cause an elevation of the posterior border of the pad in the olecranon fossa. The connection between sonographic eFPS and elbow fractures is confirmed by many studies. (25,26). Although we found one study in the literature which reported sonographic elevated fat pad sign or lipohaemarthros in 8 radial head subluxations out of 42 children in our series we experienced these phenomena only in one case out of the 196 PE. (131) That child had an unreduced PE which was older than 24 hours and showed SFE positivity. The other 195 children with confirmed PE all showed normal FPS whereas the other 9 cases with eFPS or lipohaemarthros all proved to have supracondylar humerus fractures and no SFE positivity. We consider it possible that PE which is unreduced more than 6-8 hours may cause intraarticular fluid accumulation and elevated FPS. The average time between injury and definitive treatment in our hospital were 2-6 hours, and only 17 children had longer anamnesis than 12 hours. This is a potential weakness of our study because older, unreduced injuries may show other results.We would like to note if even a certain portion of older PE injuries show positive FPS without SFE positivity that would only slightly increase the clinical suspect of fractures and a few unnecessary pre-reduction radiographs.Based only by the physical findings we found 9 cases (4.39 %) which were thought to be PE by our examiners and proved to be fractures by imaging modalities.We think that a lesser problem than a tardy indication of X-rays in the case of a true fracture after a few unsuccessful and painful reduction attempts.

V.3. Sonographic diagnosis of distal forearm fractures

The diagnosis of paediatric distal forearm fractures is traditionally based on standard two-plane X-rays. (132) The presence of a fracture or epiphyseolysis, the type of injury, axial deviation or shortening are the main elements which should be determined by X-rays. The information obtained from the X-rays is usually sufficient to set up an immediate therapeutic plan. (132)

Ultrasonic diagnostics of distal forearm fractures is made possible by the characteristic injuries affecting this area. Children with open growth plates and under the age of fourteen rarely have irregular and displaced intraarticular fractures. (133) Paediatric distal metaphyseal or epiphyseal injuries show typical patterns, which can be visualisable by the sonographic mapping of the bony cortex. (86)

The six standard planes used in our clinical practice proved to be enough to determine the presence or the type of a fracture. In our study X-rays were considered as the golden standard method of diagnostics. We observed seven pseudo-positive and seven pseudo-negative sonographic results. All these results were in the first group, which needed no therapeutic interventions and no further complications were expected. The pseudo-negative cases were observed in the initial part of the study, so we suppose this error were due to the "learning curve" period.

Out of the seven children who were considered as pseudo-positive four had prolonged pain in the area if the wrist. Although the reference X-rays were negative, the presence of a cortical crease of the affected side was clear in US, when we compared it with the healthy side. We have seen these phenomena also at several ulnar fractures when only the injury of the radius was clearly visible in X-rays. **(Figure 16.)** We suppose that these were occult fractures and US proved to be more sensitive in their detection. An MRI scan could have confirmed our assumption objectively, but it was not performed due to the lack of clinical consequences.

In the group two we classified injuries which needed reduction and plaster cast immobilisation but no operative interventions. These were mostly angulated greenstick fractures or epiphyseolysis with displacements. We have not observed difference between the diagnostic efficiency of US and X-rays. Using only US, we were even able to determine the exact configuration and degree of angulation of these stable fractures. Based on these findings even the reduction manoeuvre and its checking could be performed by US. Several study with small number of cases confirm this hypothesis. So far, it has not spread at all as an accepted practice. (87,88,89) **(Figure 17.)**

The exact evaluation of unstable fractures with shortening and severe displacement was more difficult. Although there were no pseudo-negative cases in this group, the determination of exact fracture pattern was not possible only by US. These children are usually candidates for an intervention, and X-rays are essential for preoperative planning. In these cases, sonography is useful only as a screening modality to confirm the presence of a fracture which needs operative intervention.

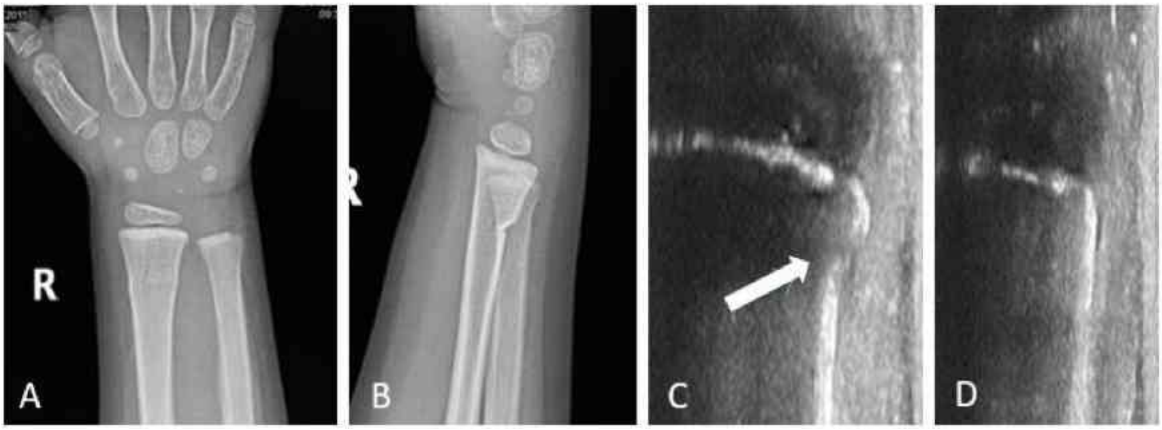

Figure 16. Ultrasound and X-ray pictures of distal forearm torus fracture

A-B: Anteroposterior and lateral radiographs show a distal radial torus fracture. Ulnar fracture is not evident **C:** Sonography shows a clear cortical crease in dorsal ulnar plane (arrow)**D:** healthy side, no cortical crease

Figure 17. Checking of reduction of a Salter-Harris type II. fracture by X-rays and sonography

A: Dorsal radial (DR)sonographic plane of Salter-Harris type II. epiphyseolysis **B:** lateral X-ray of Salter-Harris type II. epiphyseolysis **C:** DR sonographic plane of the radius after reduction **D:** lateral X-ray of the radius after reduction

A special problem may be the case of a pathological fracture. Although we have not found such patient in our study, we suppose that the sonographic sign of the inflated or eroded bony cortex would draw attention to the need of other imaging modalities. As a summary, we conclude that most of the paediatric distal forearm fractures could be diagnosed only by US. Negative cases also can be ruled out by sonography. X-rays should only be used for unstable, severely displaced fractures which need operative intervention.

V.4. Short elastic intra-medullary nailing of distal forearm fractures

The short double nailing technique is a modification of the classic ESIN method. The biomechanical principles are the same as for long diaphysial fractures, which is the concept of symmetrical splinting by 2 elastic nails, each supporting the inner cortex. (113,114,135,136) The main difference is the length and the pre-contoured curve of the nails. Ideally, the highest points of convexity of titanium elastic nails are at the level of the fracture symmetrically opposite to each other. (114) Using long nails, the highest point of the curvature shifts toward the central region of the diaphysis, so in the cases of metaphyseal or diametaphyseal fracture, it would be very eccentric from the fracture line. Using short "c"-shaped and "mini" nails, the maximal curve is at the level of the fracture and the tension within the nail provides an optimal stabilising effect. The 2 nails ensure a long contact area with the inner cortex, which is mandatory for axial stability. Using 2 nails from different entry points, but from the same level, provides rotational, translational, and bending/bowing stability. We hypothesise that "short" ESIN nails inserted at the distal metaphyseal area work the same way as conventional ESIN in a shaft fracture. In an animal study, Johnson et al have shown that at 3mm diameters or more beyond the fracture site, the length of the nail does not significantly affect the biomechanical properties of the construct. (134) The first nail is usually thicker (2.5-3 mm diameter) then the implants which are used in conventional forearm ESIN techniques. (2-2.5 mm) This is necessary because short nails have the greatest tensing effect in the broad diametaphyseal zone of the radius. The main role of the second nail is to increase rotational stability. We usually choose a thinner nail for the second one (2-2.5 mm diameter) to minimise the chance of a potential iatrogenic fracture. We have not experienced differences in rotational stability using a thinner second nail, but insertion was easier. If we choose a thinner first nail (1.5–2 mm), flexion-extension stability significantly decreases. Stability was tested under intraoperative fluoroscopy in maximally dorsal-extended and palmar-flexed position of the hand. We achieved the best stability with 2.5 - 3 and 2 - 2.5mm diameter nail combinations. The insertion points (Lister tubercle and radial dorsal side of the radius) are the well-known insertion places of conventional radial ESIN nails. Both areas are located proximally to the physeal plate thus an iatrogenic growth plate injury can be prevented. (113,114) It is very important to visualise both the dorsal and the radial entry points adequately to avoid iatrogenic injury to the long extensor pollicis tendon and the superficial radial nerve. Incorrect insertion points or malposition of the entry holes can jeopardise the physeal plates, the sensory branch of the radial nerve, or the tendons. (113,114) The insertion of a second nail becomes obsolete in the mono-elastic nailing technique because rotatory stability is given by the End Cap® implant. End Cap® also protects soft tissues. Fixation with one nail reduces the risk of the two insertion points but needs a wider incision, because tendons should be carefully protracted due to the size of the End Cap® implant.

Using double elastic nailing, we have observed only mild complications like skin irritation which was caused by the end of the dorsally inserted and relatively too long nail under the skin. We hypothesise that this problem can be attributed to improper cutoff of nails during the learning curve period of the technique. When nails are cut in a maximally palmar-flexed position of the wrist just below the level of the skin, this irritation problem ceases. The use of End Cap® implant also eliminated this problem.

Anatomical reduction is not an absolute requirement treating these kinds of fractures due to the remodelling capacity of the distal radius. Although we always strive to achieve an accurate anatomical reduction this is not always possible with closed techniques in the case of oblique fractures. We observed several moderate secondary dislocations in the first postoperative week, but they were in the remodelling range. Further secondary displacement was not observed. One child had a greater secondary dislocation which exceeded the expected remodelling capacity, but he also regained full function to the 24th postoperative week and anatomic reduction after two years. In this case radiological remodellation took a longer time but did not affect functional recovery. Fractures which were stabilised with one nail and soft tissue protectors have not shown tendency for secondary dislocation. By the end of the follow-up, all X-rays showed anatomical reduction. We have not observed any growth disturbances.

None of the children needed a long rigid cast postoperatively. In our practice we applicate a short rigid splint immediately after operation which was changed to a removable brace in the second postoperative day. The brace was removed when the child dared to start using his hand without pain. Fifteen smaller children (under the age of 7) needed brace treatment for four weeks. In their cases the reason for longer brace treatment was rather the uncertainty of cooperation.

For the time being it is not possible drawing any conclusions about the superiority of the two versions of short elastic intramedullary nailing and percutaneous pinning due to the lack of randomised studies. We think that the greatest advantages of our techniques are the early mobilisation with a short splint, the elimination of potential growth plate injuries and pin-related complications. Further prospective and biomechanical studies are required to verify our initial good experiences.

IV.5. Intra-operative sonography of radial elastic stable intramedullary nailing

Among the muscles involved in thumb movement, the extensor pollicis longus (EPL) tendon of the hand is considered the most consistent structure with the least variation among individuals. (137) Lister's tubercle is a prominent and easily visible landmark in the dorsal side of the radius by US. (138) The exact ethology of paediatric EPL injury in forearm fractures is still a question of debate. In adult populations direct injury, increased pressure in the third extensor compartment, poor vascularisation, chronic mechanical irritation caused by an implant, callus formation or spontaneous idiopathic rupture may be considered as pathogenic factor theoretically. (139,140,141,142) Most of the paediatric EPL injuries found in the literature are related to dorsal entry elastic nailing, it seems to be a unique complication of this approach. (143,144,145,146,147,148) A small cohort study identified no significant patient characteristics as any predictor of EPL rupture. (145) In a study of 9 paediatric ruptures the nail entry site was directly related to the location of EPL. (149) Direct injury of the tendon during insertion, or chronic irritation caused by the end of the nail can lead to tendon rupture. (148) In a six years period in our institution (between 2010 and 2016) we have performed 354 dorsal entry radial nailing procedures and found 7 EPL injuries retrospectively. Four cases were identified as acute (<one week after surgery) 3 as chronic (>one week postoperatively) injury. During reoperation, we found 6 complete ruptures. In all chronic and in one acute case extensor indicis tendon transfer has been performed. Direct repair was possible in 2 acute cases.

In one case rupture of the EPL tendon was not confirmed intraoperatively: the tendon was mechanically obstructed by the nail, and this caused the block of motion. The reposition of the implant has solved the problem. We hypothesise that a late rupture would have occurred without our early intervention. Cutting and bending the nail under the skin and above the level of the tendon helps to reduce the risk of skin irritation. (150)

Reviewing the literature and our experiences we concluded that optimisation of the insertion points and the position of the extraosseal end of the nails can reduce the risk of both acute and chronic ruptures. Intraoperative ultrasound has been proven an easy and useful tool for visualising these optimal reference points. We found that exact sonographic differentiation of Lister's eminence and transverse view of EPL were easily feasible. The visualisation of the end of the nail, and the determination of its position to Lister's eminence and tendon during insertion is more difficult and technically demanding. Despite this latter fact using sonographic guidance took an average extra 5 minutes during operations. Two times the longitudinal views of tendons were not clearly identifiable. We think this was rather a technical problem in the early learning curve period.

We think that with the increasing application of musculoskeletal ultrasound intraoperative use will also become more common. With appropriate training, an application of IOP-US can be a valuable addition of image intensifier and can become part of the daily surgical routine.

VI. Conclusions

US is an effective diagnostic modality in the screening of distal paediatric forearm fractures.

US shows the same diagnostic efficacy as X-rays in the exact identification of fractures without displacements and angulated greenstick fractures.

Occult radius torus fractures in children may be detected more accurately by US.

US can detect unstable and severely displaced distal forearm fractures, but X-rays are mandatory for exact fracture identification and therapeutic plan.

Paediatric elbow fractures can be screened by point of care ultrasound

Using five standardised US planes increases the diagnostic efficacy of paediatric elbow fractures.

Occult paediatric elbow fractures can be detected by US

In younger children US may give more accurate information about the exact nature of the fracture than X-rays.

The differential diagnosis of pulled elbow can be safely confirmed by a standardised two-planes US method.

Short intramedullary elastic nailing may be an alternative to percutaneous pinning in the treatment of severely displaced paediatric distal metaphyseal fractures.

Using short intramedullary nailing in distal paediatric forearm fractures there is a need only a short cast for one or two weeks postoperatively.

Intraoperative sonography may reduce the risk of extensor pollicis longus tendon injury during dorsal entry elastic intramedullary nailing of the distal radius.

The diagnostic and therapeutic options presented in my dissertation seem very promising in the treatment of paediatric forearm and elbow fractures.

However, it is important to note that our conclusions must be scientifically further strengthened. High level evidences are unavailable in the literature that would clearly demonstrate the effectiveness of ultrasonic fracture diagnostics. There are currently no comparative studies to demonstrate the advantages of short elastic nailing to other techniques. Ultrasound assisted musculoskeletal operations mean new perspective, which utility are confirmed only by a few papers currently. Increasing the evidence of the methods presented in the dissertation to a higher level and creating a legal background is the challenge of the future.

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Clinical Case Report

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Short, double elastic nailing of severely displaced distal pediatric radial fractures

A new method for stable fixation

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Abstract

Rationale: Short double elastic nailing is a minimal invasive, modified ESIN (elastic stable intramedullary nailing) technique for severely displaced distal radial fracture in children. The aim of this technical report is to introduce our new method and evaluate the final results of the procedure.

Patient concerns: We reviewed retrospectively 24 patients who underwent short double elastic nailing due to distal radial fractures between November 2012 and December 2015. Indications for surgery included closed, severely displaced, unstable metaphyseal or diametaphyseal fractures of the radius.

Intervention: The fractures were stabilized by 2 prebent short elastic titanium nails inserted from the distal side of the fracture. In cases of associated ulnar fracture, a classic anterograd ESIN nailing was also performed. Patients were mobilized immediately in a removable short splint which was removed after 1 to 2 weeks. There has been no additional splinting or casting.

Outcomes: There were 17 males and 7 females with an average age of 9.8 years (range, 4–16 years). The right hand was involved in 16 cases and the left hand in 8 cases. The average follow-up was 17.8 months (range, 7–28 months). Of the 24 patients, 3 presented irritation of the skin, which resolved after removal of the radial nail. All the patients regained full range of motion without any complications.

Lessons: Our technique is an effective, safe, and easily learnable procedure for unstable fractures of the distal third of the radius. It achieves good functional and radiological results, and allows early mobilization without the need of casting. Avoiding the physeal plates, we reduce the risk of iatrogenic postoperative deformity. Further prospective and biomechanical investigations are necessary to verify our experience.

Abbreviations: ESIN = elastic stable intramedullary nailing, K-wire = Kirschner wire.

Keywords: children, diametaphyseal radial fracture, distal forearm fracture, elastic nail

1. Introduction

Distal and severely displaced pediatric metaphyseal radial fractures with total rupture of the periosteum are generally considered unstable.[1] Although the remodeling potential of distal radius fractures is very good in childhood, a subgroup of severely displaced and unstable distal pediatric forearm fractures are candidates for operative fixation because acceptable reduction cannot be maintained in a conservative way.

These injuries are usually candidates for closed reduction and minimal invasive fixation.[1–5] Operative osteosynthesis technique of pediatric wrist fractures is optimally minimally invasive, physis sparing, and maintains an acceptable and painless reduction.

Many of these techniques do not respect physeal plates.[2,6] Most operative methods need complementary 4 to 6 weeks of postoperative immobilization by casting.[1–7]

Current available techniques (modifications of Kirschner wiring or conventional elastic stable intramedullary nailing [ESIN]) have about the same rate of mild complications. Growth disturbance is a rare, but represents a very rare severe complication of transepiphyseal wire placement. Considering this fact and the drawback of the 4 to 6 weeks of cast immobilization of the conventional techniques, we looked for a solution which eliminates these problems.

In our report, we would like to introduce our modified ESIN method for operative treatment of severely displaced pediatric distal metaphyseal or metadiaphyseal radial fractures.

With 2 short and prebent, retrograde elastic titanium nails inserted proximal to the distal radial physis, a very stable stabilization can be achieved without the need for a prolonged period of cast immobilization. The nails do not cross the physeal plates, so the possibility of postoperative physeal arrest is reduced.

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Figure 1. Pre- and postoperative x-rays of displaced distal forearm fracture.

2. Patients and methods

We reviewed retrospectively 24 patients who underwent operations due to severely displaced distal forearm or diametaphyseal radial fracture between November 2012 and December 2015. All patients were treated with short double prebent intramedullary nails. Fifteen patients had isolated radial, and 9 children had associated ulnar fracture as well. There were 17 boys and 7 girls with an average age of 9.8 years (range, 6–16 years). The right hand was involved in 16 cases and the left hand in 8 cases. Indications for surgery included closed fractures with total radial or dorsal displacement and shortening. We excluded open fractures, physeal injuries, and pathological fractures. All procedures were performed under general anesthesia and C-arm image intensifier control. A single-shot antibiotic prophylaxis was routinely used. All children were treated by 3 surgeons experienced in the ESIN and percutaneous pinning technique as well. The parents were informed about other treatment options. We began immediately with a postoperative mobilization program and applied a short removable splint. The degree of anatomic reduction was confirmed on plain radiographs obtained at the first, fourth week, and sixth month postoperatively. Nails were removed 6 to 36 weeks after the operation in general anesthesia or in local anesthesia. Average follow-up was 17.8 months (range, 7–28 months).

Considering the fact that our method is a modification and special application of the conventional and existing ESIN technique, an ethical approval was not requested by the Ethical Committee of our institutions for this retrospective study. Clinical application of the modified technique has been accepted and permitted in 2009 by our medical review board by the Hungarian Pediatric Trauma Committee and by the Hungarian Pediatric Surgery Committee. Possible benefits, risks, and complications, along with other methods, were explained to all parents of each child, and an informed consent was obtained by them.

3. Operative technique

Patients are under general anesthesia. The arm is extended and placed in a pronated position on a fluoroscopically translucent table. X-ray images of the lateral position and anteroposterior position before operation are shown in (Figs. 1 and 2). The first step is closed reduction under image intensifier. If reduction cannot be achieved by single manual manipulation a 2 to 3 mm diameter Kirschner wire (K-wire) or sharp elastic nail is inserted to the fracture gap from a dorsal stab incision. Using the pin as a lever arm, the distal fragment is raised up and slid forward onto the proximal end. After successful reduction, we determine the insertion points of the short elastic nails. The first is the dorsal site of distal radius, the area of Lister tubercle, just proximal to the physeal line of the radius. After skin incision, we gently dissect the soft tissues, and with an awl we open the medullary canal. A "C"-shaped prebent short and relatively thick (8–12 cm long and 2.5–3.5 mm diameter) titanium elastic nail is inserted into the distal medullary canal of the radius. The nail is gently moved forward along its curvature until its distal end enters the medullary canal of the proximal fragment. Then moderate force is applied, and the nail tip becomes impacted. In this position, the convex side of the nail faces the fracture line of the anterior cortex when observing from a lateral view. After insertion of the first nail, we determine the entry point for the second one. It is the distal radial site of the radius, just proximal to the growth plate.

Figure 2. Pre- and postoperative x-rays of displaced distal forearm fracture.

The second nail is usually thinner (2–2.5 mm in diameter) and also prebent to a "C"-form shape. Similarly to the technique described above, this nail is advanced forward along a radioulnar and distal to proximal curvature. After reaching the medullary canal of the proximal fragment, the nail is pushed further with a controlled force, until tightness is achieved. Observing from an AP-view, the convex side of the nail faces the ulnar cortex of the radius (Fig. 3). If the prebent curve of the short nail is not sufficient (the "C" shape is too flat), the end of the nail will get stuck in the ventral cortex. An overbent nail end, however, cannot be inserted into the proximal medullary canal. In this situation, the nail is pulled back, and the degree of the curvature is corrected. By pushing forward a malpositioned nail, an additional iatrogenic ventral or dorsal cortical fracture can occur, so it is forbidden to use uncontrolled force during nail insertion.

3.1. Postoperative care

The first 1 to 2 weeks, a short, removable splint is applied. Sport and hard physical activity is restricted for 6 weeks, but full range of movement can begin within a few days.

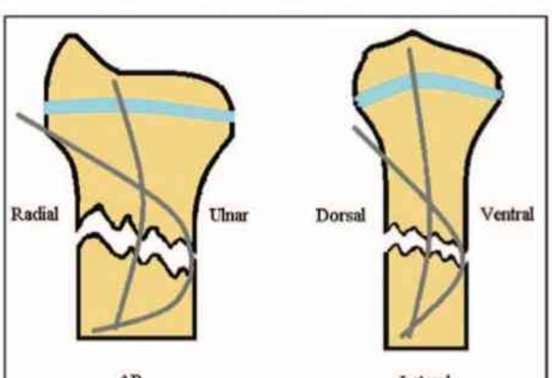

Figure 3. Position of the prebend short elastic nail is shown in the semantic picture.

4. Results

Of the 24 patients, 3 presented irritation of the skin, which resolved after a relatively early removal of the radial nail. In the sixth postopertive week, all patients regained full range of motion. We have not observed any infection, tendon, nerve, or growth plate injury during the follow-up time. Average operational time was 19 minutes (range, 7–53 minutes). The necessary splinting time was reduced to an average 1 to 2 weeks. Usually, a short removable splint was sufficient for early pain-free mobilization. In the follow-up x-rays of the patients, 20 cases were considered as anatomic, 2 as good, and 2 as acceptable reduction. All the x-rays made 6 months postoperatively showed anatomic reduction, and there has been no sign of growth disturbance at the area of the distal radius.

5. Discussion

The gold-standard operative method for pediatric distal radial fracture is closed reduction and percutaneous pinning.[2–8] Although the many variations of percutaneous pinning are simple and effective in unstable distal radial fractures, they bear many potential complications and disadvantages as well.[8–12] Kirschner-wire-related complications are well known: migration of the pins, superficial infections, damage to the growth plate, skin irritation, and insufficient biomechanical ability to maintain the reduction without casting.[8–10,13–15] This latter fact is the main drawback of this technique: in addition to the discomfort associated with operation, it is usually necessary to wear a long or short cast at least for 4 to 6 weeks postoperatively.[2,3,5–9] Fractures in the area of the diametaphyseal junction represents a special problem: they are usually located too distally to be treated by classic ESIN and too proximal for conventional Kirschner wire fixation.[2,6] Lieber et al[2] used transepiphyseal pinning in these cases. Although the chance of a iatrogenic physeal injury is very small, a physeal arrest and progressive deformity can be a potential complication of any transepiphyseal stabilization.[13–15] Others suggest a specially prebent long, physis-sparing elastic nail to eliminate this problem.[16–18] All of these methods require postoperative plaster-cast immobilization.[2,6,16–18] Analyzing our own cases of pediatric distal radial fractures treated by percutaneous pinning between 2008 and 2014 (n = 184), we found a total complication rate of 16.84% retrospectively.

Superficial infection occurred in 8 children, skin irritation in 14, migration of the wires in 5 cases, unacceptable redislocation in 2 cases, and growth disturbance and postoperative deformity in 2 cases.

Using double elastic nailing, we have observed only mild complications like skin irritation which was caused by the end of the dorsally inserted and relatively too long nail under the skin. We hypothesize that this problem can be attributed to improper cutoff of nails during the learning curve period of the technique. When nails are cut in a maximally palmar-flexed position of the wrist just below the level of the skin, this irritation problem ceases.

Cutting off the nails outside the skin is also a possibility to eliminate this complication, although until now we sank each nails under the skin.

Anatomical reduction is not an absolute requirement treating these kinds of fractures due to the remodeling capacity of the distal radius. More severe dislocations (more than 30–40°) and older children (boys aged >12 years and girls aged >10 years) need reduction to the range of the remodeling capacity. K-wire osteosynthesis needs additional cast immobilization. Redislocation can occur even with properly applied casting and wiring because certain types of fractures (i.e., diametaphyseal configuration) are highly unstable. The x-ray results of our technique were all within the remodeling range, and they did not show even minimal tendency of redislocation. This indicates the superior stability of double elastic nailing to percutaneous pinning.

Our technique is a modification of the classic ESIN method. The biomechanical principles are the same as for long diaphyseal fractures, which are symmetrical splinting by 2 elastic nails, each supporting the inner cortex.[19–23] The main difference is the length and the precontoured curve of the nails.

Ideally, the highest point of convexity of titanium elastic nails is at the level of the fracture symmetrically opposite each other.[23] By long nails, it is directed toward the central region of the diaphysis, so in the cases of metaphyseal or diametaphyseal fracture, it would be very eccentric from the fracture line. Using short "C-shaped and mini" nails, the maximal curve is at the fracture, and the tension within the nail provides an optimal memory effect. The 2 nails ensure a long contact area with the inner cortex, which is mandatory for axial stability. Using 2 nails from different entry points, but from the same level, provides rotational, translational, and bending/bowing stability. We hypothesize that "short" ESIN nails inserted at the distal metaphyseal area works the same way as conventional ESIN in a shaft fracture. In an animal study, Johnson et al[19] have shown that at 3 mm diameters or more beyond the fracture site, the length of the nail does not significantly affect the biomechanical properties of the construct.

We use thicker nails compared to conventional techniques. This is necessary because short nails have the greatest tensing effect in the broad diametaphyseal zone of the radius. For the second nail, we usually choose a smaller one because its main role is to add more rotational stability and thus we minimize the chance of a potential iatrogenic fracture. We have experienced differences in rotational stability using a thinner (2–2.5 mm) second nail, but insertion was easier. If we choose a thinner first nail (1.5–2 mm), flexion-extension stability significantly decreased. Stability was tested under intraoperative fluoroscopy in maximally dorsal-extended and palmar-flexed position of the hand. We achieved the best stability with combination of 2.5 to 3 and 2 to 2.5 mm nail diameters.

The insertion points (Lister tubercle and radiodorsal side of the radius) are the classic places for the insertion of conventional ESIN nails, located proximal to the physis, thus avoiding the possibility of iatrogenic growth plate injury. It is very important to visualize the dorsal and radial entry point adequately to avoid iatrogenic injury to the long extensor pollicis tendon and the superficial radial nerve. Incorrect insertion points or malpositions of the entry holes can jeopardize the physeal plates, the sensory branch of the radial nerve, or the tendons, which are also potential complications of the classic ESIN method.[24–27] Advantages of our technique are the early mobilization with a short splint and the elimination of potential growth plate injury. We think that our technique is a minimally invasive, easily learnable alternative operative method, when compared to percutaneous pinning in metaphyseal, and plate or transepiphyseal osteosynthesis in cases of diametaphyseal-displaced fractures of the forearm of radius. Further prospective and biomechanical studies are required to verify our initial experience.

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Observational Study

Medicine

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Intraoperative sonography may reduce the risk of extensor pollicis longus tendon injury during dorsal entry elastic intramedullary nailing of the radius in children

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Abstract

Extensor pollicis longus tendon (EPL) injury is a potential complication of dorsal entry radial elastic nailing technique in children. The aim of this study was to investigate if intraoperative ultrasonographic guidance can reduce the risk of (EPL) injury.

Correlation between sonographic and operative findings were examined first in 6 adult cadavers. Position of Lister's tubercle, EPL, and extraosseal end of the elastic nail were detected by ultrasound imaging during a minimally invasive dorsal entry nailing. Radial slope of Lister's eminence was determined as a safe and easily identifiable entry point for opening the medullary canal. Extraosseal ends of the nails were bended in a slight radial direction and cut immediately beneath the skin in a maximally palmar-flexed wrist position. Cadaveric dissections followed our procedures all correlated with ultrasonographic findings, we have not seen tendon damage, obstruction or friction by the implant's end.

After cadaveric experiments, we began using intraoperative sonography for monitoring elastic nail insertion in pediatric radial fractures.

Between January 2015 and November 2016, 77 pediatric closed diaphyseal radial fractures were operated by dorsal approach ESIN under intraoperative sonographic checking.

Procedures were executed by 2 orthopedic surgeons experienced in ESIN technique with basic musculoskeletal ultrasonographic qualifications.

Sonographic identification of EPL and Lister's tubercle in the transverse view was possible in all cases. Determination of the position of the nail end to EPL was also possible in all cases. Mean distance of the transverse view center of the EPL and nail was 0.49 cm (range 0.3–0.62 cm, SD = 0.66). Based on the sonographic transverse view, the operator decided repositioning the nails by 2 patients.

We have not found EPL injury postoperatively. All patients were followed for at least 12 months after operations. Nails were removed in all children without further complications.

Intraoperative sonography helps determining optimal insertion point and the risk of EPL injury may be reduced during dorsal entry approach.

Although the procedure is relatively easy, authors take note that surgical and sonoanatomic knowledge, basic sonographic skills and experience in the ESIN technique are equally necessary for its successful application. A greater number of cases is necessary to confirm our initial promising experiences.

Abbreviations: ECRB = extensor carpi radialis brevis tendon, ECRL = extensor carpi radialis longus tendon, EPL = extensor pollicis longus tendon, ESIN = elastic stable intramedullary nailing, LT = Lister's tubercule.

Keywords: children, corsal entry elastic nailing, EPL, ESIN, extensor pollicis longus tendon injury, radius fracture

1. Introduction

Flexible intramedullary nailing (ESIN) of displaced and unstable forearm diaphyseal fractures has become the gold standard operative method in children in the past decades.[1,2]

Elastic stable intramedullary nailing of the radius can be carried out from 2 entry points. These are the radial (distal radial side proximally from physis) and the dorsal approaches (through Lister's tubercle)[3] (Fig. 1A and B).

Both approaches have potential complications. Radial entry point can cause a 2.9% rate of transient and 0.3% rate of permanent injury to the superficial branch of the radial nerve whereas dorsal approach can have a 2.6% rate of extensor pollicis longus tendon rupture.[4] Due to the consequences of these complications, recent studies and the original description advocate using the lateral approach.[3,5,6]

Considering that lateral entry ESIN technique is disadvantageous in distal radial diaphyseal fractures and radial nerve may be a source of painful neuroma,[4,7] we were searching for safer ways to reduce the risk of the dorsal approach.

We hypothesized that ultrasonographic checking of the EPL and positioning the end of the nail during insertion in a safe zone can reduce the risk of any damage.

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The authors have no conflicts of interest to disclose.

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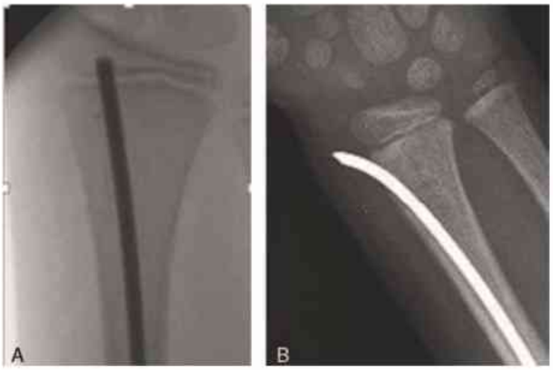

Figure 1. (A) X-ray of dorsal entry elastic nailing. (B) X-ray of radial entry elastic nailing.

2. Methods

Approval of the cadaveric and intraoperative diagnostic study was permitted by our Institutional Medical Board in 2014 November. Ethical permission for cadaveric experiments and clinical use of intraoperative sonography was approved by the Ethics Committee of Péterfy Hospital, in 2014, December.

First, we performed cadaveric examinations on six adult humans.

EPL and Lister's tubercle was visualized by high frequency (14–20 MHz) ultrasound imaging.

After sonographic determination of the insertion points, we positioned an elastic nail through Lister's tubercle according to standard dorsal technique. Position of the EPL relative to the elastic nail was examined from transverse and longitudinal planes.

We bent the extraosseal end of the nail in a slight radial direction and cut beneath the skin in a maximally palmar-flexed wrist position.

This was followed by preparation of the area and comparing the sonographic and anatomic findings (Fig. 2).

Cadaveric dissections all correlated with ultrasonographic findings: distance of EPL and nail was median 0.5 cm (range: 4.4–5.2 cm) clinically, and 0.48 cm (range: 0.44–0.5 cm) sonographically. There was no tendon damage, obstruction or friction.

Following our cadaveric experience, we began using intraoperative ultrasound during elastic nailing of pediatric radial fractures.

A written informed consent was obtained from the parents of all patients.

Between January 2015 and November 2016, 77 radial fractures were operated by dorsal entry elastic nailing with ultrasonic guidance. Inclusion criteria were children with closed and displaced radial or forearm fractures which were candidates for operative ESIN technique. We excluded children with closed growth plates, open fractures and comminuted fractures which could not be stabilized by intramedullary nailing. Patients' age were between 4 and 15 years and had closed and displaced radial or forearm fractures with open growth plates.

We used aseptically isolated high frequency linear probes and sterile gel for the intraoperative technique. First, we determined the insertion point. After skin incision and soft tissue separation, we targeted the radial slope of Lister's tubercle with a sharp

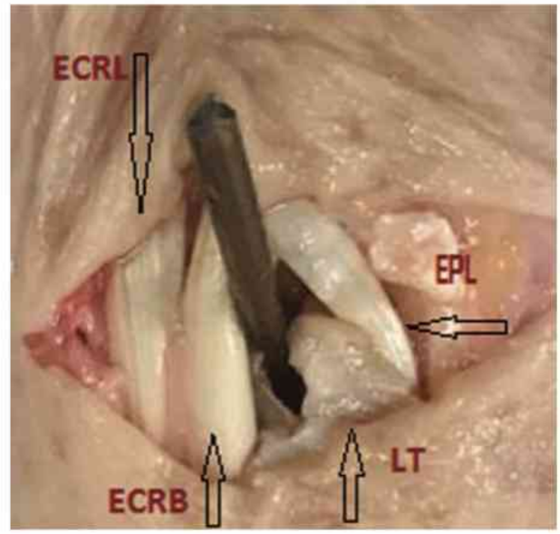

Figure 2. Relation of the end of the nail to the surrounding structures in dorsal approach. (adult cadaveric preparation) ECRL = extensor carpi radialis longus tendon, ECRB = extensor carpi radialis brevis tendon, LT = Lister's tubercule.

Kirschner wire (Fig. 3). After we pressed the wire softly to the bone we checked its position with image intensifier and ultrasound. Medullary canal opening with a sharp awl was also monitored sonographically and an elastic nail of 2 to 2.5 mm diameter was inserted.

Operative technique and fracture reduction were made according to standard protocol.[3]

After cutting the end of the nail, we rechecked its position relatively to Lister's tubercle.

EPL has been also checked in longitudinal and transverse plane, we analyzed its relation to the extraosseal part of the nail (Figs. 4–6).

Continuity of the tendon has been checked by dynamic examination while passively flexing and extending the wrist and the thumb.

Figure 3. Sonography -assisted aiming of the radial side of Lister's tubecule with a K-wire.

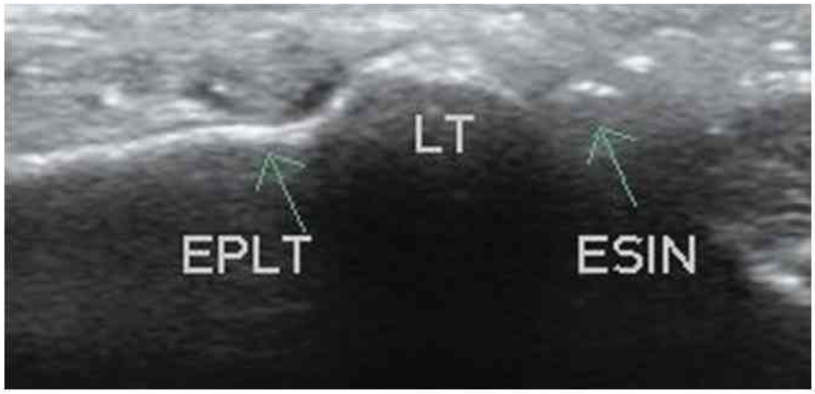

Figure 4. Transverse intraoperative sonographic view of the nail and tendon. ESIN = elastic stable intramedullary nail, EPL = extensor pollicis longus tendon, LT = Lister's tubercule.

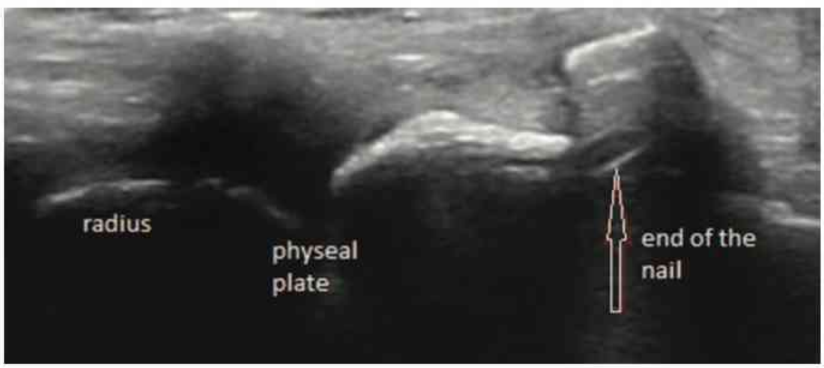

Figure 5. Longitudinal intraoperative sonographic view of the nail and the radius: Extensor pollicis longus tendon is not visualized.

In patients where we found that the nail was too close to the tendon or the EPL got stock during dynamic assessment), we corrected its position.

Procedures were executed by 2 orthopedic surgeons experienced in ESIN technique and with musculoskeletal ultrasonographic qualifications.

3. Results

Ultrasonographic identification of EPL and Lister's tubercle in the transverse view was possible in all children.

Determination of the position of the nail to EPL was also possible in all patients. Mean sonographically measured distance

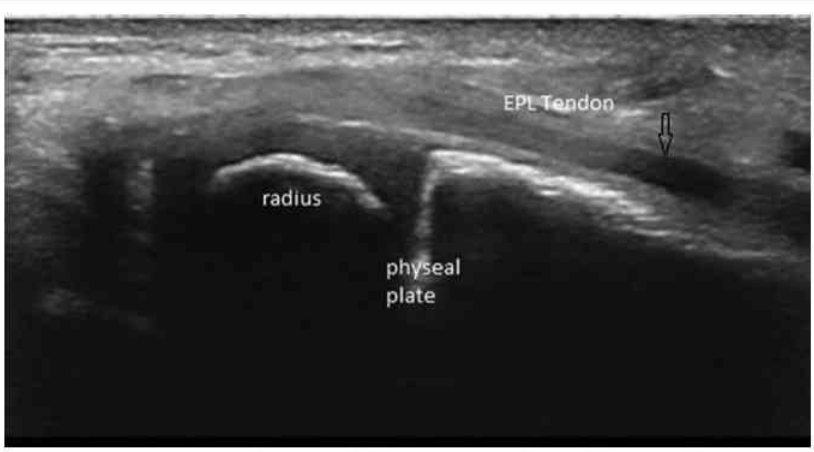

Figure 6. Longitudinal intraoperative sonographic view of the radius and the EPL tendon. Nail is not visualized in this plane. EPL = extensor pollicis longus.

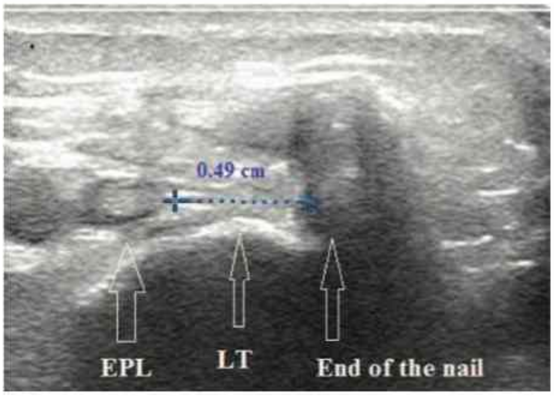

Figure 7. Measurement of the distance of the nail and the tendon in transverse sonographic view. LT=Lister's tubercule, EPL=extensor pollicis longus tendon.

of the transverse view center of the EPL and nail was 0.49 cm (range: 0.3–0.62 cm, SD=0.66) (Fig. 7).

Longitudinal view of EPL was not clearly defined in 2 cases.

Based on the sonographic transverse view (insertion points were 2 close (< 0.3 cm) to EPL) the operator decided repositioning the nails by 2 patients.

On one occasion EPL movement was not seen with dynamic assessment, although the tendon was clearly identifiable. In this case, we decided re-bending the end of the nail. After correction, we were able to identify normal tendon movement.

Sonographic procedures took average 5 minutes (range: 2–8 min. mean=4.8 min) extra time during operations.

We have not found EPL injury or septic complications postoperatively. All patients were followed for at least 12 months after operation. Nails were removed in all children without further complications.

4. Discussion

Among the muscles involved in thumb movement, the extensor pollicis longus (EPL) tendon of the hand is considered the most consistent structure with the least variation among individuals.[8] Lister's tubercle is a prominent and sonographically easily visible landmark in the dorsal side of the radius.[9]

Intra- and postoperative usage of high-frequency ultrasound in musculoskeletal trauma is a relatively new method for various purposes.[10,11] Recently, few authors have reported good initial results with sonography in different musculoskeletal operations.[12,13]

Using sonography is advantageous due to the visualization of the relationship of various soft tissues (i.e. tendons, nerves, arteries) and implants which are invisible to x-rays, and the lack of radiation.[10–13] Ultrasound is also a reproducible tool for identification of EPL and its pathologies.[9]

The exact etiology of pediatric EPLT injury in forearm fractures is still a question of debate.

In adult populations direct injury, increased pressure in the third extensor compartment, poor vascularization, chronic mechanical irritation caused by an implant, callus formation or spontaneous idiopathic rupture may be considered as pathogenic factor theoretically.[14–17] Although, there may be other causes,[18,19] since most of the pediatric EPL injuries found in the literature are related to dorsal entry elastic nailing, it seems to be a unique complication of the dorsal approach.[20–23]

A small cohort study identified no significant patient characteristics as any predictor of EPL rupture.[20] In a study of 9 pediatric ruptures the nail entry site was directly related to the location of EPL.[5] Direct injury of the tendon during insertion, or chronic irritation caused by the end of the nail can lead to tendon rupture.[23]

In a six years period in our institution (between 2010 and 2016) we have performed 354 dorsal entry radial nailing procedures and found 7 EPLT injuries retrospectively. Four cases were identified as acute (<one week after surgery) 3 as chronic (>one week postoperatively) injury. During reoperation, we found 6 complete ruptures. In all chronic and in one acute case extensor indicis tendon transfer has been performed. Direct repair was possible in 2 acute cases. In one case rupture of the EPL tendon was not confirmed intraoperatively: the tendon was mechanically obstructed by the nail, and this caused the block of motion. The reposition of the implant has solved the problem. We hypothesize that a late rupture would have occurred without our early intervention.

Cutting and bending the nail under the skin and above the level of the tendon helps to reduce the risk of skin irritation.[24] Reviewing the literature and our experiences we came to the conclusion that optimisation of the insertion point and the position of the extraosseal end of the nails can reduce the risk of both acute and chronic ruptures. Intraoperative ultrasound has been proven an easy and useful tool for visualizing these optimal reference points. We found that exact sonographic differentiation of Lister's eminence and transverse view of EPLT were easily feasible. The visualization of the end of the nail, and the determination of its position to Lister's eminence and tendon during insertion is more difficult and technically demanding. In spite of this latter fact using sonographic guidance took an average extra 5 minutes during operations. Two times the longitudinal views of tendons were not clearly identifiable. We think this was rather a technical problem in the early learning curve period.

Although the procedure seems very easy, the authors take note that surgical and sonoanatomic knowledge, sonographic skills, and experience in the ESIN technique are equally necessary for its successful application.

5. Conclusion

We came to the conclusion that intraoperative sonography may reduce the risk of the dorsal entry ESIN technique. The method is simple, harmless and only slightly increases the surgical time.

A greater number of cases is necessary to confirm our initial promising experiences.

Author contributions

Conceptualization: Marcell Varga, Sándor Pintér.
Data curation: Szilvia Papp.
Investigation: Marcell Varga, Nikoletta Gáti, Tamás Kassai, Szilvia Papp.
Methodology: Marcell Varga.
Project administration: Marcell Varga.
Resources: Marcell Varga.
Supervision: Sándor Pintér.
Writing – original draft: Marcell Varga.
Writing – review & editing: Marcell Varga.

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Gyermekkori csuklótáji törések diagnosztikája ultrahanggal

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Bevezetés és célkitűzés: Prospektív tanulmányunk célja a gyermekkori csuklótörések ultrahang-diagnosztikájának ismertetése és két mozgásszervi centrum eredményének bemutatása.
Módszer: 2011 januárja és 2015 decembere között 467, 1–15 év közötti gyermek ultrahangvizsgálatát végeztük el. Valamennyi gyermek zárt sérülést szenvedett el és nyitott epiphysisfugával rendelkezett. Az ultrahangvizsgálatot rezidensek és ortopéd-traumatológus, illetve gyermeksebész szakorvosok végezték közvetlenül az elsődleges fizikális vizsgálatot követően, 7–14 MHz frekvenciatartományú lineáris transzducerekkel. Az eredményeket hagyományos kétirányú csukló-röntgenfelvételekkel hasonlítottuk össze.
Eredmények: 97%-os szenzitivitást és 96%-os specificitást találtunk. Elmozdulással és komolyabb klinikai konzekvenciával járó törések ultrahanggal is mind felismerésre kerültek.
Következtetés: A mozgásszervi ultrahangvizsgálat a gyermekkori csuklótáji törések igazolásának vagy kizárásának rendkívül hatékony eszköze a napi gyakorlatban.
Orv Hetil. 2017; 158(24): 944–948.

Kulcsszavak: ultrahang, gyermekkor, csuklótörés

Ultrasonographic diagnosis of distal pediatric forearm fractures

Introduction and aim: The aim of our prospective study was to evaluate the effectivity of sonographic diagnosis of pediatric wrist fractures and analyzing the results of two pediatric musculoskeletal centers.
Method: Between 2011 January and 2015 December 467 children aged 0–15 with closed wrist injuries and open growth plates were sonographically and radiologically evaluated by an orthopaedic surgeon or a resident in trainee. Sonography was performed immediately after physical examination with linear probes of 7–14 Mhz frequency. Results were compared to conventional two plane wrist x-rays.
Results: We found 97 sensitivity and 96 specificity of the sonographic evaluation. Fractures with dislocations and more serious clinical consequences were never missed.
Conclusion: Musculoskeletal ultrasound is a very effective tool in daily routine for diagnosing or excluding pediatric wrist fractures.

Keywords: sonography, pediatric, wrist fracture

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A csuklótáji törések világszerte a gyermekkor leggyakoribb sérülései közé tartoznak, illetve növekvő tendenciát mutatnak [1–4].

A Péterfy Sándor Utcai Kórház-Rendelőintézet és Baleseti Központ Gyermekambulanciáján évente mintegy 1500 gyermek ambuláns vizsgálata történik csuklótáji sérülés miatt. A pontos diagnózis felállítása az esetek túlnyomó részében röntgen- (RTG-) képalkotással történik [4, 5]. A hagyományos kétirányú RTG-felvétel elhanyagolható egészségügyi kockázatot jelent, ugyanakkor világszerte hangsúlyozott törekvés az ionizáló sugárzás lehetőség szerinti minimalizálása [6, 7].

Az utóbbi években számos közlemény jelent meg a gyermekkori csuklótáji törések „point of care” ultrahangos (UH-) diagnosztikájáról [8–12]. A legtöbb szerző egyetért abban, hogy a módszerrel nemcsak a törés ténye, hanem konfigurációja és elmozdulásának mértéke is a RTG-vizsgálatokkal lényegében egyező effektivitással értékelhető [13].

Magyarországon – tudomásunk szerint – gyermekkori törésdiagnosztika céljából ultrahangot rutinszerűen, elfogadott protokoll szerint sehol nem alkalmaznak, illetve magyar nyelvű beszámoló ilyen irányú alkalmazásról eddig nem jelent meg.

A Péterfy Sándor Utcai Kórház-Rendelőintézet és Baleseti Központ Gyermektraumatológiai Osztályán 2011, a Pécsi Tudományegyetem Gyermeksebészeti Centrumában 2014 óta végzünk gyermekkori ultrahangos törésdiagnosztikát.

Prospektív tanulmányunk célja a módszer ismertetése és a két mozgásszervi centrum eredményének bemutatása.

Betegek és módszer

Vizsgálatunk során a gyermekeket – az ambulanciára való beérkezésüket követően, a primer fizikális vizsgálattal egy időben – lineáris fejjel ellátott ultrahangkészülékkel is megvizsgáltuk. A vizsgálatok során összesen három különböző típusú ultrahangkészüléket használtunk. A lineáris fejek frekvenciatartománya 7–14 MHz-ig terjedt.

A két gyermektraumatológiai centrumban 2011. december és 2015. december között 467 dokumentált esetben végeztünk UH-diagnosztikát. A vizsgálatokat a két intézetben összesen hat orvos végezte (két ortopéd-traumatológus szakorvos, két ortopéd-traumatológus szakorvosjelölt, egy gyermeksebész szakorvos, valamint egy gyermeksebész rezidens) „point of care” módon, azaz közvetlenül a fizikális vizsgálatot követően, a RTG-felvételek elkészülése előtt.

A vizsgálatba csak olyan gyermekeket vontunk be, akiknél a fizikális vizsgálat és a klinikum alapján kizárólag kétirányú csuklófelvétel indikációja állt fenn. Kizárólag nyitott növekedési porcok mellett értékeltük az eredményeket. Kizártuk a vizsgálatból azokat az eseteket, ahol a fájdalom nem pontos lokalizációja, a kooperáció hiánya vagy az anamnézis alapján egyéb testtájék RTG-vizsgálata is szükségessé vált (os scaphoideum törése miatt négyirányú felvétel, alkartörés gyanúja miatt alkar-RTG-felvétel stb.).

A vizsgálat háton fekve vagy ülő pozícióban történt. Az érintett végtagot a gyermek hasára vagy az előtte lévő vizsgálóasztalra helyeztük *(1. és 2. ábra)*.

1. ábra | Háton fekvő gyermek csuklósérülésének vizsgálata ultrahanggal

2. ábra | Transzducertartás ventralis radialis síkban

A transzducerrel hat különböző, a végtag tengelyével megegyező, longitudinális síkban jártuk körül a csuklót, így egy dorsoulnaris, dorsoradialis, lateroradialis, medioulnaris és két ventralis leképezést nyertünk *(3. ábra)*.

Az ellátás ezután a hagyományos protokoll szerint (kétirányú csukló-röntgenfelvétel) folytatódott.

Az ultrahang- és fizikális vizsgálat által felállított diagnózis pontosságát a RTG-felvételekkel összevetve értékeltük *(4. és 5. ábra)*.

3. ábra | A transzducer által leképzett síkok sémás ábrája

A vizsgálatok eredményeinek pontos feldolgozásához egy értékelőlapot szerkesztettünk. A lapon a vizsgáló személy – a beteg adatainak kitöltése után – a primer vizsgálatot követően bejelölte, hogy a klinikum és az ultrahangvizsgálat alapján véleményez-e törést, ha igen, milyen jellegűnek ítélte meg azt. A RTG-felvétel elkészültét követően felvezetésre került a klinikus által a röntgen alapján véleményezett diagnózis. A radiológus által kiadott lelet szintén felvezetésre került, így a vizsgálati eredményeket objektíven tudtuk összehasonlítani.

A fenti kritériumoknak megfelelően 467 esetet értékeltünk.

Eredmények

270 (57,8%) esetet a primer RTG alapján pozitívnak, 197-et (42,2%) negatívnak találtunk. Ultrahangvizsgálattal 263 esetet értékeltünk pozitívnak és 204-et negatívnak *(1. táblázat)*.

1. táblázat | A RTG- és UH-vizsgálattal értékelt pozitív és negatív esetek megoszlása (n = 467)

	RTG	UH
Pozitív	270	263
Negatív	197	204

Az észlelt töréseket a klinikai konzekvenciát illetően (konzervatív kezelés, repozíciós igény, műtéti igény) három csoportba osztottuk. Az álnegatív és álpozitív esetek megoszlását az egyes csoportokon belül is vizsgáltuk *(2. táblázat)*.

4. és 5. ábra | Oldalirányú csukló-RTG- és ennek megfelelő UH-felvétel

Az álnegatív eseteket, amikor ultrahanggal nem sikerült a RTG-felvételeken látható törést igazolni (n = 7), az elmozdulás nélküli, klinikai konzekvenciával nem járó csoportokban észleltük. Álpozitív eredményeket, amikor az ultrahanggal törésnek véleményezett törés RTG-fel-

2. táblázat Az álpozitív és álnegatív ultrahangos esetek megoszlása az egyes klinikai csoportokon belül

Az észlelt törések felosztása klinikai konzekvencia alapján, n = 270	RTG pozitív	UH álnegatív	UH álpozitív
Csekély klinikai konzekvenciával járó esetek, átmeneti rögzítést, fájdalomcsillapítást, gipszet vagy rögzítő brace-t igénylő torustörések és elmozdulás nélküli metaphysistörések	n = 188 (70%)	n = 7	n = 7
Helyi érzéstelenítésben vagy narkózisban való helyretételt, gipszrögzítést igénylő szöglettöréssel járó metaphysistörések a csontcorticalis folytonosságával	n = 52 (20%)	0	0
Műtéti ellátást igénylő, a periosteum-szakadással járó nagy fokban elmozdult törések	n = 30 (11%)	0	0

vételen nem igazolódott (n = 7), szintén csak ebben a csoportban találtunk. A fentiek alapján a szenzitivitást 97%-nak, a specificitást 96%-nak találtuk.

Három, primeren álpozitív esetben a nem szűnő fájdalmak miatt később végzett ismételt RTG-vizsgálat calusképződést igazolt, emiatt ezeket utólag pozitívnak minősítettük.

A diagnosztikát végző személyek hatékonysága között szignifikáns különbséget nem találtunk. A RTG- és UH-vizsgálattal észlelt 14 ellentmondó diagnózist a tanulási fázis elején, az első 100 eset során állították fel.

Megbeszélés

A gyermekkori csuklótáji törések diagnózisát, illetve a további terápiás terv felállítását hagyományosan RTG alapján végezzük. A RTG-vizsgálattal igazolható a törés, epiphyseolysis ténye, tengelyeltérésének mértéke [14, 15]. További terápiás tervet a gyermek korának, az elmozdulás mértékének figyelembevételével állítjuk fel.

Gyermekkori ultrahangos törésdiagnosztikát rutinszerűen kevés helyen végeznek a világon. Ennek szervezési, szakmai és anyagi okai is lehetnek – a gyermeksérültek elsődleges ellátása világszerte más-más rendszer alapján történik. A sürgősségi osztályok személyi és tárgyi felszereltsége is jelentős különbséget mutat [16, 17].

A sikeres diagnosztikához gyermektraumatológiában és musculoskeletalis szonográfiában is jártas szakember szükséges. A módszer előnyei ugyanakkor egyértelműek. Gyors, a beteg számára fájdalmatlan, noninvazív és talán a legfontosabb, hogy ionizáló sugárzással nem jár [8–13, 17, 18].

Vizsgálataink és a nemzetközi irodalom alapján ultrahanggal a terápiás konzekvenciával járó törések jelenléte, illetve hiánya egyértelműen detektálható és a RTG-nel csaknem megegyező objektív információ nyerhető [8–13, 19].

Az ultrahangos törésvizsgálat lehetőségét a régió gyermekkori sajátosságai teremtik meg. Tizennégy éves kor alatt, illetve nyitott növekedési porcok mellett a felnőttkorra jellemző ízületi lépcsőképződéssel járó, illetve öszszetett darabos distalis radiustörések nagyon ritkák. A típusos gyermekkori csuklótáji törések (epiphyseolysisek, metaphysis-, torustörések stb.) konfigurációja jellegzetes, a csontcorticalis megváltozásának típusos képével jár.

A vizsgálati technikáról

A lineáris transzducer által kibocsátott, a csontról teljes egészében visszaverődő ultrahangnyalábok által képzett rajzolat, az adott sík csontcorticalis vonalát a röntgenhez hasonlóan jeleníti meg. Különbség, hogy míg a RTG-felvételen szummációs képet látunk, az UH által alkotott kép mindig a transzducer vastagságának megfelelő területről mutat egy szeletet. Ezért fontos, hogy a vizsgálófejet mindig merőlegesen, billentés nélkül helyezzük a csontok hossztengelyére, hogy a képalkotás pontos legyen. A klinikai gyakorlatban a hat standard sík alkalmazása (radiodorsalis, ulnodorsalis, ulnoulnaris, radioradialis, radiopalmaris és ulnopalmaris) elegendő, bár elméletben a csuklót a transzducerrel körbejárva korlátlan számú szelet leképezhető. További különbség, hogy a dorsalis, illetve palmaris irányból felhelyezett transzducer az oldalirányból készült, az ulnaris, illetve radialis irányból képzett szonográfiával pedig az ap. RTG-felvétellel nyerünk analógiába vonható képet *(2. ábra)*. A vizsgálat során a gyermekek karját csak minimálisan kell mobilizálni, ez az alkar és a csukló egyidejű rögzítésével minden esetben probléma nélkül kivitelezhető.

Vizsgálatainkban „hagyományos”, alacsonyabb felbontású fejet (7 MHz) és „high resolution”, magas felbontású transzducert (14 MHz) is használtunk. Bár a magas felbontású fejekkel értelemszerűen részletgazdagabb kép nyerhető, a distalis radius- és ulnatörések diagnosztikai hatékonyságának tekintetében nem találtunk különbséget a gépek között. A nagy elmozdulással, teljes periosteum-átszakadással járó, általában operatív indikációt jelentő esetek ultrahangos pontos értékelése nehezebb, ilyenkor a szonográfiás kép alapján a törés ugyan egyértelműen megállapítható, de annak pontos konfigurációjára nehéz következtetni. Ugyanakkor tapasztalataink azt mutatják, hogy a megfelelő gyakorlat megszerzését követően a diagnosztikai hatékonyság is növekszik.

A tévesen felállított diagnózisoknak (álpozitív, illetve álnegatív esetek) a terápiára kiható érdemi konzekvenciája elméletileg nincs, mivel gyakorlatunk alapján a végtag rögzítése (gipszsín, brace) még töréssel nem járó csukló- és alkarsérülések esetében is indokolt a gyermek panaszai függvényében, és kontrollvizsgálattal az ilyen esetek kiszűrhetőek.

Érdemi terápiát igénylő, elmozdulással járó esetek vizsgálata során nem találtunk különbséget az ultrahang-és a röntgendiagnosztika hatékonysága közt. Az eltérő diagnózisok az első 100 esetszám során születtek, így az eljárás „tanulási görbéjének” szerepe sem elhanyagolható.

Figyelemre méltó, hogy három betegnél az ultrahangvizsgálattal a klinikus törést diagnosztizált, míg a primer röntgen negatívnak bizonyult. Mivel ezeknek a gyermekeknek elhúzódó panaszai voltak, ismételt RTG-vizsgálatot végeztünk. A négy héttel később készült RTG-felvételen periostealis callus ábrázolódott, amely egyértelműen korábban lezajlott okkult törésre utal. Ezek alapján feltételezhető, hogy bizonyos esetekben az ultrahang- a röntgenvizsgálatnál szenzitívebb is lehet.

Elvileg differenciáldiagnosztikai problémát jelenthetnek a patológiás (például juvenilis ciszta) alapon kialakuló törések. Bár a vizsgált betegek között ilyen jellegű elváltozás nem fordult elő, feltételezzük, hogy a csontcorticalis felfújt szerkezetének, illetve az esetleges lágyrész-folyamat jelenlétének egyértelműen fel kell hívnia a figyelmet a további képalkotás (CT, MRI stb.) szükségességére.

Következtetés

Megfelelő helyi, tárgyi és személyi feltételek megléte esetén (rendelkezésre álló UH-készülék, amelynek segítségével a vizsgálat a primer fizikális vizsgálattal egy időben és egy helyen elvégezhető, gyermektraumatológiai ellátásban jártas szakember mozgásszervi ultrahangkezelési ismeretekkel) a fenti módszer segítségével az ellátás gyorsasága és hatékonysága jelentősen növelhető. Az irodalomban fellelhető tanulmányok hasonló eredményekről számolnak be, ugyanakkor nagy esetszámú feldolgozást keveset találtunk [13].

Hangsúlyozni szeretnénk, hogy tanulmányunkkal nem azt szándékoztuk sugallni, hogy a gyermekkori csuklótörések ellátásában a RTG-vizsgálat felesleges, hanem azt, hogy tapasztalataink alapján az UH-vizsgálat nagyon effektív, hasznos kiegészítője lehet a napi ambuláns ellátásnak, illetve bizonyos feltételek teljesülése esetén a röntgenvizsgálat alternatívája is lehet.

A diagnosztikai módszer esetleges önálló alkalmazása, illetve kiterjesztése ugyanakkor számos jogi és gyakorlati kérdést is felvet (mikor, milyen dokumentáció szükséges az objektív értékeléshez, milyen képesítéssel lehetne végezni stb.), amelyek megválaszolása, illetve a megfelelő protokollok kidolgozása még várat magára. A szerzők további prospektív vizsgálatokat terveznek ezek eldöntésére.

Anyagi támogatás: A kézirat megírása anyagi támogatásban nem részesült.

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Érdekeltségek: A szerzőknek nincsenek érdekeltségeik.

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Gyermekkori csonttörések vizsgálata ultrahanggal

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ÖSSZEFOGLALÁS

Bár az ultrahanggal végzett törésdiagnosztika lehetősége évtizedek óta ismert, a módszer mégsem terjedt el rutinszerűen. A magas frekvenciájú transzducerek, illetve nagy felbontású készülékek elterjedésével, továbbá a klinikusok által végzett „point of care" vizsgálatok egyre népszerűbbé válásával a szonográfiás törésdiagnosztika ismét az érdeklődés középpontjába került. Gyermekkorban szerepe felértékelődik, mert csökkentheti a felesleges röntgenvizsgálatok számát, illetve gyorsíthatja az akut ellátást. A kedvező tapasztalatok és az egyre növekvő számú tanulmány ellenére ugyanakkor a mai napig nem állnak rendelkezésünkre magas szintű evidenciák. Cikkünkben összefoglaljuk az akut gyermektraumatológiai ellátás során alkalmazható ultrahangos törésdiagnosztikai lehetőségeket, ezek előnyeit és potenciális klinikai alkalmazásukat. A szerzők megjegyzik, hogy a bemutatott módszerek kiegészítő lehetőségek, céljuk nem a röntgenvizsgálatok teljes helyettesítése, hanem a diagnosztikus hatékonyság növelése, biztonságosabbá tétele, valamint a felesleges sugárexpozíció csökkentése.

Kulcsszavak: ***Diagnosztika; Gyermekkor; Radiográfia; Törések; Ultrahang;***

M. Varga, L. Tóth, G. Garancsy, K. Ribes, S. Pintér: Ultrasound diagnostics of fractures in children

Although ultrasound diagnostics of bone fractures has been known for decades, the method has not spread widely. With the development of high-frequency and high-resolution devices, as well as the growing popularity of point-of-care examinations by clinicians, sonographic fracture diagnostics have once again become the focus of interest. It is particularly important in childhood, by reducing the number of unnecessary x-ray examinations and speeding up acute care. Despite the positive experiences and the increasing number of studies, we still have no high-level evidence to date. In our article, we summarize the ultrasonic diagnostic options for paediatric bone fractures, their benefits and their potential clinical application. The authors note that the methods presented are complementary and not intended to replace X–ray examinations, but to increase diagnostic efficacy, make it safer and reduce unnecessary radiation exposure.

Keywords: ***Child; Fractures, bone – Diagnostic imaging; Point-of-Care Systems; Radiography; Ultrasonography – Methods;***

BEVEZETÉS

A magas frekvenciájú transzducerekkel végzett mozgásszervi ultrahang diagnosztika az elmúlt években jelentős fejlődésen esett át, és egyre általánosabbá vált használata az akut ellátás során is (8, 9). A nemzetközi irodalom az ultrahang ilyen irányú alkalmazását sokszor a „point of care" jelzővel illeti (22). A fenti kifejezést magyarra fordítani nehéz, de általánosságban olyan, klinikus által végzett ultrahangos gyorsdiagnosztikát jelent, ami célzott klinikai kérdésre keresi a választ. Intézetünkben 2011 óta alkalmazunk klinikus által végzett akut mozgásszervi ultrahang diagnosztikát a gyermektraumatológiai ellátás során.

A csonttörések szonográfiás diagnosztikai lehetőségéről *Leitgeb* számolt be először 1986-ban (31). Magyarországon *Farbaky Zsófia* és munkatársai írtak először a csonttörések szonográfiás vizsgálatáról (20). Bár azóta számos tanulmány született, amely az egyes testtájékok ultrahangos törésdiagnosztikájának effektivitását igazolta, a módszer nem terjedt el rutinszerűen (7, 10, 12, 25, 41, 45). Ennek több oka is lehet. Egyrészt az ultrahang diagnosztika nem alkalmazható valamennyi töréstípusnál egységesen, másrészt speciális jártasságot, szervezést igényel használata az akut ellátás során (7, 10, 12, 25). A magas frekvenciájú, nagy felbontású készülékek klinikai gyakorlatban való elterjedésének köszönhetően ugyanakkor a közelmúltban ismét az érdeklődés középpontjába került (11).

A legtöbb tanulmányt angolszász rendszerű sürgősségi osztályok végezték, a szonográfiás törésdiagnosztikát itt általában az ellátást gyorsító triage, illetve további képalkotás igénybevételének eldöntéséhez való szűrés céljából alkalmazzák (11). További kutatások igazolták az ultrahang törések észlelésében való diagnosztikus előnyeit harctéri övezetekben, illetve forrásaiban korlátozott egészségügyi ellátó helyeken (7, 12, 11). Az ultrahang ugyanakkor egyéb kiegészítő képalkotást szükségtelenné tevő definitív diagnosztikaként is használható, főleg bizonyos gyermekkori töréstípusok esetén. Ilyen irányú, hagyományosan inkább ortopéd–traumatológus által végzett diagnosztikáról a német típusú ellátási rendszerekben számoltak be leginkább (2, 16–18, 24, 27).

Gyermekkorban a mozgásszervi ultrahang szerepe felértékelődik, mivel ionizáló sugárzással nem jár, relatíve olcsó, non-invazív diagnosztikai módszerről van szó. Cikkünkben áttekintést nyújtunk a gyermekkori ultrahangos törésdiagnosztika módszeréről, illetve bemutatjuk a lehetséges alkalmazási területeket.

FIZIKAI ALAPOK

A csontot érő ultrahangnyaláb lényegében teljes egészében reflektálódik. A csöves csontok corticalisát, arra merőlegesen és hossztengelyére párhuzamosan tartott lineáris transzducerről kibocsátott ultrahangnyalábokkal, egyenes vonalként lehet leképezni. A modern készülékekkel akár már néhány tizedmilliméter nagyságú corticalis megszakadás is vizualizálható (12). A gyermekkorra jellemző, csontcorticalis deformációval járó sérülések (torus törések, angulatióval járó zöldgally törések) típusos mintázatot adnak (7). A törési résben képződő fokozatosan csontosodó, kezdetben lágy callus jelenléte az ultrahangnyalábok részleges visszaverése miatt jóval hamarabb látható. Ezt a törésgyógyulás korai detektálásában, illetve callodiastasis ellenőrzésében (végtaghosszabbítás) lehet kihasználni (1. ábra) (26, 50). A nagyrészt porcos elemeket tartalmazó, még minimális ossificatiót mutató, hagyományos rontgen számára sokszor „láthatatlan" ízületi alkotóelemek (apophysis magok, avulsiós fragmentumok) is sokszor vizualizálhatóak ultrahanggal (46).


a b c

1. ábra
a) Koraszülött gyermek femur diaphysis törése
b) A femurtörés ebben az életkorban 1–2 hét alatt konszolidálódik, a kezelés konzervatív
c) Két héttel később készült ultrahangfelvételen a csont corticalison kialakuló dombszerű előboltosulás szolíd callus jelenlétére utal, a felhelyezett brace biztonsággal eltávolítható, röntgen kontroll nem szükséges

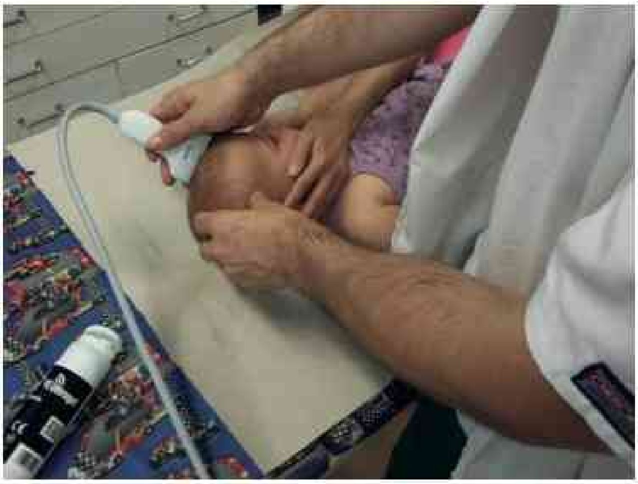
SZEMÉLYI ÉS TÁRGYI FELTÉTELEK

A célzott törésdiagnosztikára irányuló ultrahangvizsgálathoz a szonográfiás alapképzettség már elegendő lehet, ugyanakkor fontos szempont a gyermektraumatológiai ellátásban való jártasság is. Bár a csontok corticalisa egyszerűbb, alacsonyabb frekvenciájú (10–12 MHz) lienáris transzducerekkel is leképezhető, a környező lágyrészek vizsgálata, illetve az egyes rétegek határozott elkülönítése csak magasabb frekvenciájú (>10–18 MHz), nagyfelbontású készülékkel valósítható meg. Az ellenoldal vizsgálatát összehasonlítás céljából általában érdemes elvégezni. A modern készülékekben a betegek rögzített ultrahangos képei tárolhatók, visszakereshetők.

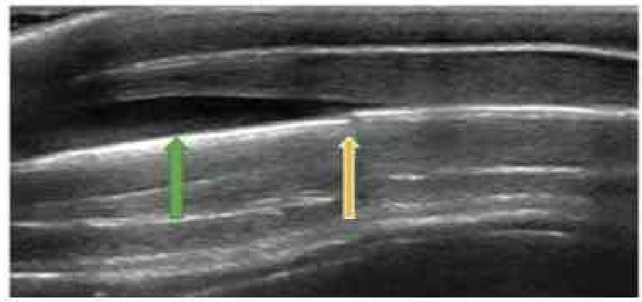
ALKALMAZÁSI LEHETŐSÉGEK TESTTÁJÉKOK SZERINT

Koponyatörések

Gyermekkorban a fejsérülés az egyik vezető halálok. A gyermekkori koponya trauma optimális diagnosztikus algoritmusa, illetve a potenciálisan súlyos következményekkel járó esetek kiszűrése a mai napig szakmai vita tárgya. A hagyományos kétirányú koponyaröntgen-felvételek alacsony szenzitivitásuk, míg a CT felvételek magas sugárterhelésük miatt nem alkalmazhatóak minden esetben és rutinszerűen. Boltozati, körülírt duzzanat, illetve fluktuáló terime esetén az ultrahang értékes kiegészítő képalkotó eljárás a koponyacsont-folytonosság megszakadásának igazolásában. Hátránya, hogy csak akkor informatív, ha a törés az erőbehatás területén alakul ki. A vizsgálatokat legalább két, egymásra merőleges síkban el kell végezni. Bár fejsérülés esetén az ultrahang csak kiegészítő diagnosztikus metódus, prioritását a hagyományos röntgenfelvételekkel szemben számos tanulmány igazolta (13, 36, 39). (*2–3. ábra*).



2. ábra *Koponya vizsgálata ultrahanggal*



3. ábra *Koponya boltozati csont törése. Az ultrahang felvételen jól látszik a csont corticalis megszakadása (sárga nyíl), illetve a subgalealis haematoma (zöld nyíl)*

Clavicula törések, proximalis humerus törések

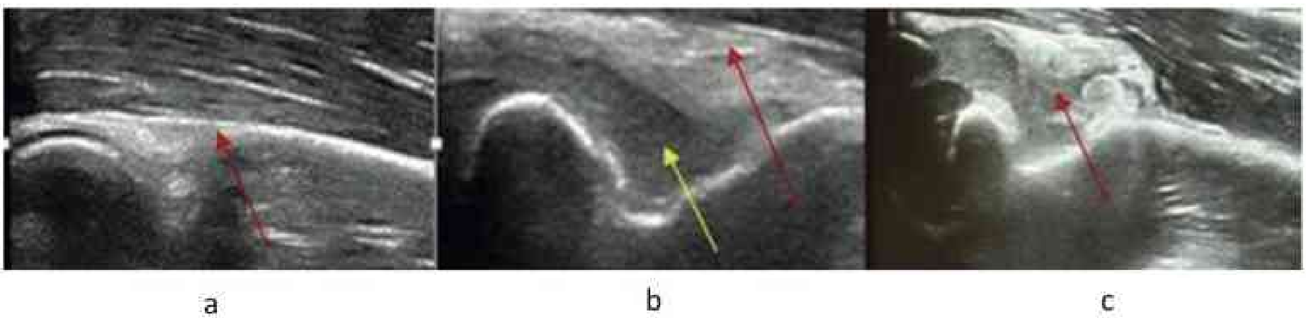
A gyermekkori kulcscsont- és proximalis felkarcsont-törések többnyire típusos mintázatot mutatnak, és a legtöbb esetben konzervatívan kezelhetőek. A humerus, illetve proximalis metaphysis periostealis folytonosság megtartottságával járó angulált, vagy torus törései, valamint a clavicula hasonló sérülései a röntgenfelvételekkel lényegében egyező effektivitással igazolhatóak. Nagy dislocatióval járó, esetlegesen műtéti ellátást igénylő sérülések során az ultrahang igazolja a súlyosság fokát, de a pontos konfiguráció megítéléséhez a röntgen elengedhetetlen (1, 15) (*4–5. ábra*).

4. ábra
Proximalis humerus törés vizsgálata. A három síkból végzett vizsgálat a gyermek vállának fájdalmas mobilizációja nélkül elvégezhető

5. ábra
Proximalis humerus metaphysis torus jellegű törésének ultrahang- és röntgenképe.
A fehér nyíl az epiphysis fúgára, a piros nyíl a torus törésre mutat

Könyöktáji törések

A gyermekkori könyöktáji törések nagyon gyakoriak tízéves kor alatt. A diagnosztikát nehezíti, hogy a könyökízület több csontosodási magból fejlődik, amelyek megjelenése változó. A könyökízület porcos részeit érintő törések röntgenfelvételen sokszor egyáltalán nem láthatóak, pedig akár műtéti indikációval is járhatnak. Ultrahang segítségével vizsgálható a dorsalis szonográfiás zsírpárna jel (az intraarticularis és extrasynovialis zsírpárna kóros elhelyezkedésének, a zsírpárna dislocatiójának) jelenléte, illetve hiánya, amely a radiológiai zsírpárna jelnél sokkal szenzitívebb. A vizsgálat során a fossa olecrani fölé helyezett transzducerrel igazolható, hogy a zsírpárna dislocatiójakor, annak előboltosulása a humerus corticalisának szintjét meghaladja-e. Negatív esetben a klinikai konzekvenciával járó intraarticularis törés jelenléte lényegében kizárható. További standard síkok vizsgálatával a diagnosztika még hatékonyabbá tehető (1, 17, 18) (*6–7. ábra*).



6. ábra
a) Szonográfiás zsírpárna jelek a fossa olecraniban (longitudinális metszet). A szabályos elhelyezkedésű dorsalis echodús zsírpárna (normális zsírpárna jel) lényegében az intraarticularis törés jelenlétét kizárja (piros nyíl)
b) Elevált zsírpárna jel. A normál echodús zsírpárna (piros nyíl) kiemelkedik a kóros ízületi folyadékgyülem (sárga nyíl) miatt. Ízületi vérzésre, illetve okkult könyöktáji törésre utal.
c) Lipohaemarthros. A fossa olecraniban inhomogén bevérzésre jellemző, belső echokat tartalmazó, kóros folyadékgyülem megjelenése könyöktáji törés jele (piros nyíl)

7. ábra
Elmozdulás nélküli radialis condylus törés ultrahang- és röntgenképe

Distalis alkartörések

A gyermekkori csuklótáji törések a gyermekkor leggyakoribb sérülései. A szonográfiás törésdiagnosztika legáltalánosabban tanulmányozott régiója. Több tanulmány is igazolta, hogy a szonográfia ugyanolyan hatékony, mint a röntgen a gyermekkori distalis radius és ulnatörések esetén (1, 44, 48, 51). A vizsgálat hat standard sík felvételével néhány perc alatt elvégezhető (48). Remodellációs kapacitást meghaladó angulációval járó törések, vagy dislocált epiphyseolysisek esetén a repozíció eredményessége röntgen helyett ultrahangvizsgálattal is ellenőrizhető (51) (*8–9. ábra*).

8. ábra
Jelzett ventralis billenéssel járó distalis radius metaphysis törés röntgen- és ultrahangképe

9. ábra
Salter–Harris II-es epiphyseolysis ultrahang- és röntgenképe, valamint a repozíció után készült ultrahang- és röntgenfelvételek

Kézközépcsont és ujjtörések

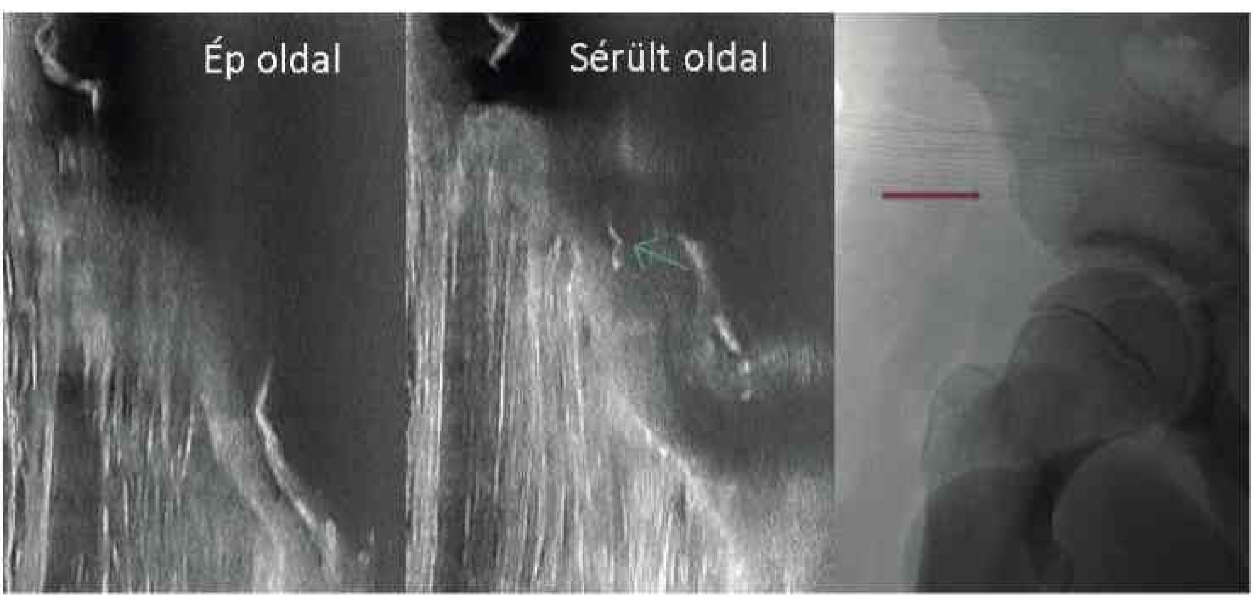
A hosszú ujjak PIP és DIP ízületi avulsiói, epiphyseolysisei, illetve a metacarpusok diaphysisét, végpercét érintő törések egyaránt jól vizualizálhatóak gyermekkorban. Hasonlóan a csuklótájékhoz az V-ös metacarpus fej billenéssel járó törései reponálhatóak is szonográfiás ellenőrzés mellett. A műtéti indikációt képező tengelyeltérések, diastasisok ugyancsak észlelhetőek, de ezekben az esetekben pontos ábrázolás csak röntgen igénybevétele mellett lehetséges (4, 47).

Csípőtáji sérülések

Számos gyermekkori, a csípőt érintő patológiás folyamattal először baleseti ambulancián jelentkeznek elsődleges ellátásra, mert sokszor valamilyen sérüléssel hozzák összefüggésbe. A csípő elülső ferde síkból végzett ultrahangos gyorsdiagnosztikájának a hagyományos röntgendiagnosztika mellett számos előnye lehet. Bár a csípőízületi folyadékszaporulat ritkán utal traumára, jelenléte, rutin szűrése, gyermekkori csípő- és térdtáji fájdalmak esetén nagyon sok segítséget nyújthat egyes kórképek megerősítésében, illetve kizárásában.

A három leggyakoribb gyermekkori csípőtáji folyamat – transitorius coxitis, Legg–Calvé–Perthes kór, illetve serdülőkori combfej epiphyseolysis – fennállása jóval hamarabb megállapító. Serdülőkori combfej epiphyseolysis kezdeti stádiumában az ultrahangon látható lehet az ízületi folyadékszaporulat, valamint az epiphysis fúga kiszélesedése, így szenzitívebb lehet a röntgennél, amely ilyenkor gyakran még semmilyen elváltozást nem mutat (14, 35).

A részben elcsontosodott medencetáji apophysis magok serdülőkori avulsiós törései többnyire sportolás, illetve hirtelen nagy energiájú izomtevékenység során alakulnak ki, hagyományos röntgenfelvételekkel gyakran nagyon nehéz a megítélésük és differenciáldiagnosztikai problémát jelenthetnek. Célzott ultrahangvizsgálat megerősítheti a klinikai gyanút (*10. ábra*).

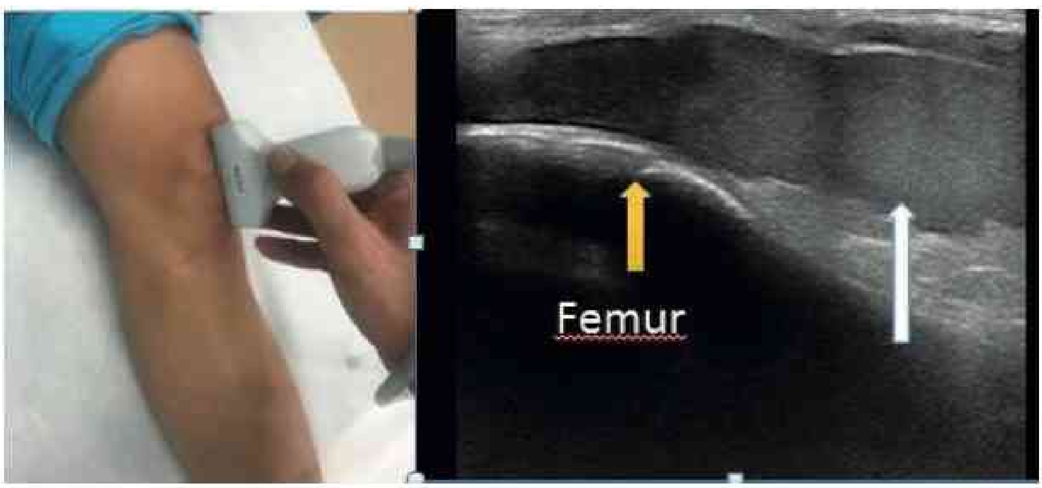


10. ábra

Spina iliaca anterior inferior avulsiós törése 15 éves sportoló gyermeknél. Míg a röntgenfelvételen csak sejthető a törés (piros nyíl), az összehasonlító ultrahangképen az ép oldallal összehasonlítva egyértelműen látható az avulsiós fragmentum (zöld nyíl).

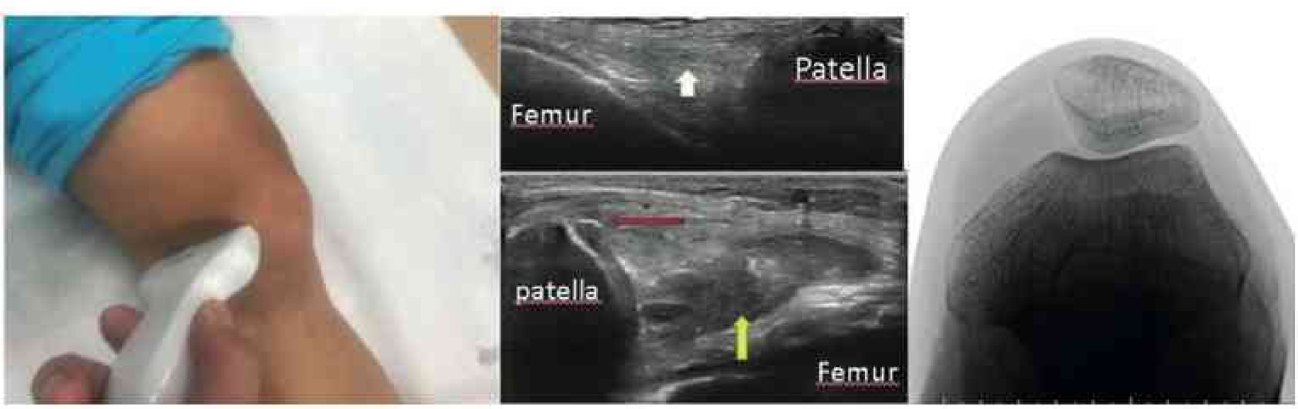
Térdtáji sérülések

A gyermekkorban jelentkező térdtáji panaszok hátterében számos patológiás folyamat húzódhat. A diagnosztikát nehezíti, hogy a gyermekek elsődleges vizsgálata sokszor egyáltalán nem mozgásszervi specialista által történik. Hasonlóan a csípőízülethez, a térdízületi folyadékszaporulat – amely szonográfiával nagyon szenzitíven, egyszerűen igazolható – mindig patológiás folyamatra (törés, szalagsérülés, gyulladás) utal. Röntgenfelvétellel nem igazolható okkult törések, porcfelszín sérülés, retinaculum avulsiós törések, amelyek terápiás konzekvenciát jelenthetnek is észlelhetőek „point of care" ultrahanggal. A fenti esetekben a legfőbb előny, hogy a gyors, sugárterheléssel nem járó és olcsó vizsgálat felhívhatja a figyelmet a további relatív sürgős diagnosztika (MRI) és terápia (artroszkópia) szükségességére (3, 6, 28, 29) (*11–12. ábra*).



11. ábra

Haemarthros genus vizsgálata és ultrahangképe. A longitudinális síkban végzett vizsgálattal látható a femur corticalisa, illetve a növekedési zóna (sárga nyíl), valamint a recessus suprapatellarisban elhelyezkedő jelentős mennyiségű, sűrű, csaknem homogén ízületi folyadékgyülem (fehér nyíl)



12. ábra

Patellaficam utáni állapot, medialis retinaculum vizsgálata. Az ép oldallal összehasonlítva látható, hogy a medialis retinaculum szabályos szerkezete (fehér nyíl) a sérült oldalon a patellán történő tapadásnál, a kis avulsiós fragmentum (piros nyíl). A retinaculum alatt folyadékgyülem látható (sárga nyíl)

Lábszártörések

Gyermekkori lábszársérülések esetén az ultrahang effektíven alkalmazható a nagy dislocatióval járó törések primer rögzítése, vagy helyretétele során a megfelelő tengelyállás ellenőrzésére, illetve konzervatív kezelés során a redislocatio kizárására.

A még csak részleges csontosodást mutató tuberositas tibiae avulsiós töréseinél is fontos szerepe lehet az ultrahangnak a sérülés fokának megítélésében.

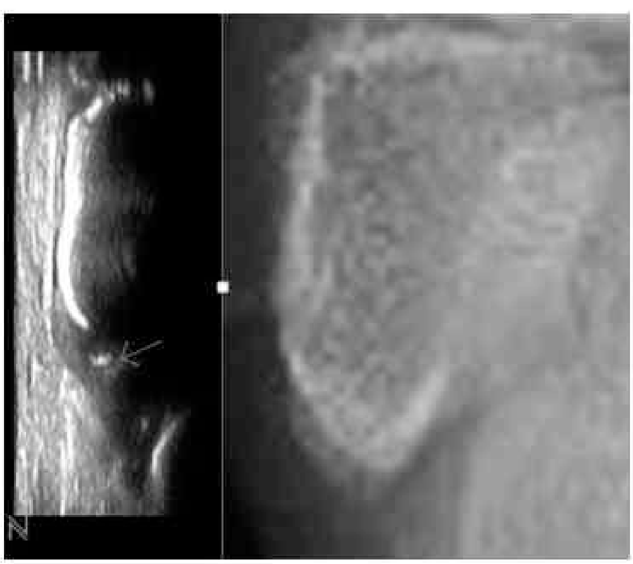
Speciális eset a kisgyermekkori kis traumára kialakuló izolált tibia infractiós sérülés (Toddler's fracture), amely a primeren sokszor negatív röntgenfelvételek miatt sokszor kifejezett differenciáldiagnosztikai problémát jelent. A csont corticalis megszakadása ezekben az esetekben általában szonográfiával igazolható (32, 37, 38)

Bokatáji törések

A gyermekkori bokatáji sérülések rutinszerűen alkalmazott diagnosztikus vizsgálata a háromirányú röntgenfelvétel. Ismert tény ugyanakkor, hogy gyermekkorban csak az esetek kevesebb, mint 5%-ában igazolódik csontos eltérés. Emiatt egyes ajánlások csak a járásképtelenséggel és nagy duzzanattal járó esetekben javasolják egyáltalán a röntgen képalkotás igénybevételét. Néhány szerző a röntgenhez hasonló diagnosztikus értékűnek találta az ultrahangot a külbokatörések kizárásában. A gyermekkora jellemző fibula distalis vég héjszerű szalagos avulsiói sokszor csak ultrahanggal vizualizálhatóak. A fentiek alapján járásképességüket megtartott, bokasérült gyermekek esetén sokkal inkább az ultrahang lenne optimális az elsődlegesen választandó képalkotó eljárásnak (19, 33) (*13. ábra*).

Lábcsont-törések

A lábujjak, metatarsusok sérülései a kéz ujjaihoz hasonló effektivitással vizsgálhatóak. Az ultrahang kifejezett segítséget nyújthat az V. metatarsus bázistörések megítélésében, valamint a törés, illetve korcsoportra jellemző apophysis magok elkülönítésében (30, 40) (*14. ábra*), illetve az avulsiós sérülések diagnosztizálásában.



13. ábra
Külboka avulsiós törés ultrahangképe. A röntgenfelvételen csak sejthető, hogy a külboka csúcsából egy kis fragmentum kiszakadt (nyíl)

14. ábra
Metatarsus bázistörés röntgen- és ultrahangképe. A törésben kialakult diastasis megítélése hagyományos röntgenfelvételen sokszor nehéz. A lateralis síkból felhelyezett transzdúcer segítségével az elmozdulás mértéke ultrahangvizsgálattal pontosan meghatározható (nyíl)

SPECIÁLIS ESETEK

Gyermekbántalmazás

Gyermekbántalmazás gyanúja esetén az ultrahang jelentős segítséget nyújthat egyéb régebbi, addig nem felismerésre került törések detektálásában. Szonográfiával a csöves csontok további potenciális sérüléseinek szűrése effektíven végezhető el, ennek különösen kisdedek, kisgyermekek subperiostealis töréseinek esetén van jelentősége. Ezekben az esetekben a callusképződés gyorsan bekövetkezik, így a törés klinikailag már kevésbé észlelhető, ha a gyermeket később viszik orvoshoz – ugyanakkor az ossificálódó csonthártya alatti haematoma jellegzetes ultrahang képe sokáig vizualizálható (34, 49).

Stressztörések

Az ultrahangnak nagy szerepe lehet különböző stressztörések korai identifikálásában. Stressztörésre utalhat a megvastagodott periosteum, a corticalis vonalának disruptiója, illetve Doppler aktivitás fokozódása, a hypervascularisatio megjelenése az érintett csontszegmens környezetében. Ezek a jelek akár hetekkel korábban is kimutathatóak, mint a röntgenfelvételen legkorábban látható morfológiai elváltozások (21, 23) (*15. ábra*).

15. ábra

Élsportoló gyermek lateralis térdfájdalmát okozó proximalis fáradásos fibulatörés. A csont corticalison látható megvastagodás már a callusképződés jele (nyíl)

MEGBESZÉLÉS

A fentiekben több olyan régiót soroltunk fel, ahol a gyermekkori ultrahangos törésdiagnosztika relatíve egyszerűen és sürgősségi ellátásban alapszintű képesítéssel is alkalmazható lenne. Az irodalomban számos beszámolót találunk egyéb csonttörések sikeres diagnosztikájáról is – ezek azonban vagy magasabb szintű szonográfiás képzettséget igényelnek, vagy jóval alacsonyabb szenzitivitású, specificitású egyedi esetek – semmiképpen nem a rutin részei (42). Az akut gyermektraumatológiai ellátás során ugyanakkor minimum az esetek 70–80%-ában a fenti régiók valamelyike sérül, így az ultrahangnak különösen nagy szerepe lehetne az ellátás gyorsításában, a differenciáldiagnosztikában, illetve a fölösleges röntgenvizsgálatok redukciójában (42).

Bár az ultrahang törésdiagnosztikai hatékonysága évtizedek óta ismert, a mai napig nem állnak rendelkezésünkre magas szintű evidenciák, amelyek a fentiekben részletezett alkalmazási lehetőségeket tudományosan alátámasztanák. Az irodalomban fellelhető számos közlemény jelentős része sürgősségi osztályok vagy egy-egy centrum által végzett relatív kisebb esetszámok alapján vonta le következtetéseit (42).

Az Európai Musculoskeletalis Radiológiai Társaság (European Society of Musculoskeletal Radiology – ESSR) 2017-ben kiadott egy közleményt, amely a mozgásszervi ultrahangvizsgálatok egyes kórképekre vonatkozó jelenlegi evidenciáit is tartalmazza. A konszenzus szerint több régió törése (könyök, térd, proximalis humerus, tibia) is vizsgálható ultrahanggal, de a jelenlegi információk birtokában ez többnyire egyéb képalkotó lehetőségek hiányában ajánlott, és az ultrahangos törésdiagnosztika hatékonyságáról egyáltalán nem állnak rendelkezésre A–típusú bizonyítékok (43).

Az Európai Orvosi és Biológiai Ultrahang Társaságok Szövetsége (EFSUMB) 2016-ban kiadott egy kifejezetten gyermekkorra vonatkoztatott ajánlást, amely egyaránt tartalmazza a módszertani, dokumentációs, személyi és tárgyi feltételeit a legbiztonságosabban alkalmazható gyermekkori proximalis és distalis humerus, valamint distalis alkari törések szonográfiás diagnosztikájának, de a módszer egyelőre nem elfogadott rutineljárás része sehol a világon (1).

Eddig egy hazai közlemény jelent meg a témában, amely distalis alkartörések ultrahangos vizsgálata során két centrum, összesen 437 esetszámát elemezve, a nemzetközi irodalomban fellelhetőekhez hasonlóan kedvező eredményre jutott (48).

Az Országos Traumatológiai Intézetben 2011 óta foglalkozunk gyermekkori szonográfiás törésdiagnosztikával, az utóbbi években több gyermektraumatológiai centrum (Budapest, Heim Pál Kórház, Pécs, Szeged) is elkezdte alkalmazását. A módszer hazai protokolljának és jogi hátterének megteremtése még várat magára.

Az egyes anatómiai régiók további nagy esetszámú, prospektív és multicentrikus vizsgálatán és a tárgyi feltételek megteremtésén túl a rutin ultrahangos törésdiagnosztika további feltétele az alapszintű musculoskeletalis ultrahangos oktatás ortopéd–traumatológiai szakképzésbe való iktatása is. A szerzők hangsúlyozzák, hogy az ultrahangos törésdiagnosztika célja nem a röntgenfelvételek mellőzése, hanem egy, a hagyományos rutin radiológiai eljárásokat kiegészítő, azt ésszerűen redukáló, ellátást gyorsító, esetenként további információkat adó költséghatékony metódus megteremtése.

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Gyermekkori nagy diszlokációval járó distalis radius metaphysis törések kezelése rövid elasztikus velőűrszegezési technikával

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ÖSSZEFOGLALÁS

A radius distalis végének törése az egyik leggyakrabban előforduló sérülésforma gyermekkorban. A nagy diszlokációval, teljes periosteum átszakadással és összecsúszással járó törések műtéti indikációt képeznek. A műtéti megoldást többnyire tűződrótos osteosyinthesis és kiegészítő 4–6 hetes gipszrögzítés jelenti. Az alkartöréseknél sikeresen alkalmazott ESIN technika (Elastic Stable Intramedullary Nailing) módosított módszereivel a növekedési porcot elkerülő, minimál invazív technikával olyan stabil szintézis érhető el, amely a posztoperatív rögzítési időt is jelentősen redukálja. Cikkünkben a rövid kettős, illetve lágyrészvédelemmel ellátott rövid monoelasztikus velőűrszegezést, ezek technikáját, illetve retrospektíven feldolgozott eredményeinket ismertetjük. 2013. október és 2017. október között két centrumban összesen 84 gyermek rövid kettős elasztikus szegezését végeztük el, míg 16 gyermeknél lágyrészvédővel ellátott monoelasztikus szegezés történt. A műtéti indikáció valamennyi gyermeknél zárt, az alkar distalis harmadára lokalizálódó, nagy diszlokációval, és mindkét corticalis átszakadásával járó metaphysis vagy dia-metaphysealis átmenetben elhelyezkedő törés volt. A physisek valamennyi esetben nyitva voltak, a gyermekek életkora 4–14 év között volt. Implantátum vándorlás nem alakult ki. Mély szeptikus szövődményt egy esetben sem észleltünk. Három esetben felületes infekció alakult ki a kettős szegezéssel ellátott csoportban, a szegek eltávolítását követően a panaszok megszűntek, a törés az eltávolítás idején már konszolidált. A kettős elasztikus szeggel ellátott csoportban összesen további 9 gyermeknél észleltünk az implantátumvég által okozott bőrirritációt. A fémek eltávolítása után ezek a panaszok maradéktalanul megszűntek. A lágyrészvédelemmel ellátott csoportban implantátum okozta irritációt nem észleltünk. Ín-, illetve idegsérülést egyik csoportban sem találtunk. Az utánkövetési idő 9 hónap – 4 év volt, valamennyi gyermek teljes, oldalazonos funkcióval gyógyult. A féléves kontroll során készült röntgenfelvételen, a remodellációs szak lezajlását követően, egy kivétellel a radiuson, valamennyi esetben anatómiai tengelyállást észleltük. A rövid szegezési technika jó alternatívája lehet a tűződrótos osteosynthesisnek. Előnye a physisek elkerülése, a mozgásstabil szintézis, a csökkent idejű és egyszerűsített külső rögzítés, és a gyermekek gyors rehabilitációja. A sikeres műtéti technika az ESIN technikában, illetve gyermektraumatológiában való jártasságot igényel.

Kulcsszavak: ***Gyermekkor; Intramedullaris töréskezelés; Radius törés; Szegezés;***

M. Varga, T. Kassai, Zs. Bíró, E. Kalóz, N. Gáti, G. Józsa, S. Pintér: Treatment of completely displaced distal metaphyseal fractures of the radius in children with short elastic nailing

Fractures of the distal radius are the most common injuries in children. Completely displaced and shortened fractures with periosteal rupture are candidates for osteosynthesis. The most common operative treatment is percutaneous pinning with rigid long cast immobilization for 4–6 weeks postoperatively. Using a modified ESIN method (Elastic Stable Intramedullary Nailing) a very stable, physis sparing, minimally invasive osteosynthesis can be achieved, without the need of long cast immobilization. In our paper we present the operative technique of short double elastic and soft tissue protected monoelastic nailing, and retrospectively analyze the results of our interventions. We reviewed retrospectively patients who underwent short double elastic or soft-tissue-protected nailing due to distal radial metaphyseal fractures between October 2013 and October 2017 in two Pediatric Trauma Centres. Indications for surgery included closed, severely displaced unstable metaphyseal or meta-diaphyseal radial fractures of the radius. We treated 84 children with double elastic and 16 children with mono-elastic short nails. Age of the patients was between 4 and 14years, and all of them had open growth plates. The average follow-up time was 18.8 months (9–48 months). We have not seen any migration of the implants. There was no deep infection either. At three children a superficial skin infection has been observed, which was eliminated by removing the nails. 9 children complained to a mild skin irritation which also resolved by implant removal. Patients with soft tissue protected mono-elastic nail have not had this complain. There was no tendon or nerve injury. All of the patients regained full range of motion without further complications. Radiological remodellation was perfect in all except one case after six months. Short elastic nailing may be a good alternative technique of percutaneous pinning. Its advantage is the physis sparing method, which is stable, and reduces the time of rehabilitation. Further prospective and biomechanical investigations are necessary to verify our experience.

Keywords: ***Bone nails; Child; Fracture fixation, intramedullary – Methods; Radius fractures – Surgery;***

BEVEZETÉS

A radius distalis végének törése az egyik leggyakrabban előforduló sérülésforma gyermekkorban (11). Konzervatív kezeléssel az esetek 80–90 százalékában (torus törések, epiphyseolysisek, periosteum folytonosságát megtartó, diszlokáció nélküli és angulációval járó metaphysis törések) kiváló eredmények érhetőek el (2).

A nagy diszlokációval, teljes periosteum átszakadással és összecsúszással járó törések ugyanakkor még gyermekkorban is műtéti indikációt képezhetnek (2, 16). Műtéti ellátás indokolt, ha a törés primeren reponálhatatlan, illetve korai rediszlokáció alakul ki, amely a várható remodellációs kapacitást meghaladja (2, 16, 19).

Gyermekkorban a distalis radius törések műtéti stabilizálásának legáltalánosabban elfogadott módszere a fedett, tűződrótos osteosynthesis és kiegészítő gipszrögzítés (8, 17, 19). A felnőttkorban használatos lemezes szintézis a physisek hiperstimulálása, a következményes növekedési zavar lehetősége és nyílt műtét miatt 14 éves kor alatt nem ajánlott.

A tűződrótos osteosynthesisnek ugyanakkor számos hátránya is ismert. A drótok elvándorolhatnak, a bevezetés helyén sokszor bőrirritáció illetve felületes infekció alakulhat ki, a törésben rediszlokáció léphet fel, illetve a szintézis csak mozgás stabil, így 4–6 hetes, a könyökízületet is immobilizáló gipszrögzítést is igényel gyakori kontrollvizsgálatokkal (7, 20, 21).

Külön problémát jelentenek a dia-metaphysis határon elhelyezkedő törések, amelyeknél a tűződrótok nem pozícionálhatóak úgy, hogy a proximalis darabot is megfelelően rögzítsék. Ezeknél a töréseknél egyes szerzők a növekedési porcon átvezetett szintézist ajánlják, bár ismeretes, hogy ezzel a későbbi növekedési zavarok kockázatát növelik (14, 15).

Az Országos Traumatológiai Intézet Gyermektraumatológiai Osztályán az elmúlt években több olyan eljárás is bevezetésre került, melyekkel a fenti problémák kiküszöbölhetőek. Az alkartöréseknél sikeresen alkalmazott ESIN technika módosított módszereivel a növekedési porcot elkerülő, minimál invazív technikával, olyan stabil szintézis érhető el, amely a posztoperatív rögzítési időt is jelentősen redukálja. Cikkünkben kizárólag a rövid kettős, illetve lágyrészvédelemmel ellátott mono-elasztikus velőűrszegezést, ezek technikáját illetve retrospektíven feldolgozott eredményeinket ismertetjük.

MŰTÉTI TECHNIKA

Kettős rövid elasztikus szegezés

A műtét általános narkózisban történik. A gyermek a hátán fekszik, karja nyújtott helyzetben karasztalon. A műtét egyes lépései képerősítő kontroll mellett történnek, amelyet célszerű a beteg láb felőli oldaláról vezetni, míg az operatőr a fej felőli oldalon ül. Vértelenítő mandzsetta alkalmazása a műtéthez nem feltétlen követelmény, de ajánlott, amennyiben a szegek bevezetési pontjait – az ín védelme céljából – kis feltárásból kívánjuk végezni. Lemosást és izolálást követően először a radius distalis végének repozícióját végezzük el. Amennyiben ez fedett manuális manőverekkel nem kivitelezhető, célszerű egy, a törési résbe dorsalis irányból bevezetett vastag tűződróttal (2.5–3 mm) segíteni a helyretételt. A drót tompa végét a törési résbe vezetve, emelő mechanizmussal, a distalis darab még jelentős összecsúszás esetén is ráemelhető a radius proximalis végére (*1. ábra*).

A repozíciót követőn kiválasztjuk a szegeket. Relatív vastag, 2.5–3-as szegeket célszerű választani, amelyeket egy körülbelül 10–12 cm hosszúságú szakaszon „C” alakúvá hajlítunk. A szeg első bevezetési pontja, dorsalisan, a Lister tuberculum radialis oldala. A velőűr megnyitását a physistől proximalisan, azt nem érintve, de ahhoz a legközelebb kell megcélozni, hogy a kis distalis darabban a szeg jó tartást biztosítson a későbbiekben. Ezt követően bevezetjük az előre meghajlított szeget úgy, hogy a legnagyobb görbülete palmaris irányba tekint. A szeget óvatosan, görbülete mentén vezetjük előre, amíg a vége bele nem akad a proximalis törtdarab velőüregébe. Ekkor a szeg megfeszül, és további kontrollált erőbehatással, még néhány cm-es szakaszon továbbvezethető a velőüregben. Optimális esetben a szeg legnagyobb görbülete a törési rés magasságában van. Fontos, hogy a szeget sem ütni, sem feszegetni nem szabad, mert ezzel további iatrogén törést okozhatunk. Ha a görbület túl nagy, és a szeg nem vezethető át a proximalis törtdarabba, vagy 1–2 cm után elakad és a nagy feszülés miatt nem vezethető tovább, célszerű visszahúzni, és korrigálni az ívén, vagy vékonyabb szeget választani.

Az első szeg bevezetését követően kerülhet sor a radialis irányból való második szeg behelyezésére. A bevezetési pont itt a radius distalis és radialis oldala a physistől proximalisan, a konvencionális ESIN technikánál megszokott módon. A második szeg a rotációt stabilizálja, így lehet vékonyabb az előzőnél, kevésbé kifejezett előrehajlítással. A radialis corticalis megnyitása után ezt a szeget is gördítve helyezzük be, a szeg konvexitása a radius ulnaris oldala felé néz. A törési résen való sikeres átjutás után ezt a szeget is néhány cm mélységben vezetjük még tovább, amíg a feszülés engedi. A két szeg proximalis vége általában 1–2 cm szintkülönbségben helyezkedik el. Amennyiben a tengelyállás nem megfelelő, a szegek óvatos pozícionálásával ilyenkor még korrigálni tudjuk. A repozíció során a kis ad latus diszlokációk nem jelentenek problémát, alapvetően a radius distalis végének remodellációs kapacitását nem meghaladó tengelyállásra kell törekedni. A gyermek korától függően 10–15 fokos dorsovolaris, illetve 5 mm-es ad latus tengelyeltérés is elfogadható, egyes esetekben a régió jó remodellációs potenciálja miatt, de alapvetően anatómiai repozícióra célszerű törekedni.

A radius stabilizálása után, az ulna törésének jelenléte esetén annak a velőűrszegezését is javasoljuk elvégezni a kellő stabilitás megteremtéséhez. Az ulna velőűrszegezése proximalis irányból történik és semmiben sem tér el a klasszikus ESIN technikánál alkalmazott elvektől.

Szeglevágás: A szegek végét hajlított kéztartás mellett, a bőr szintje alatt vágjuk le. A szegek szabad distalis végének pozícionálása különösen kritikus, mivel a túl hosszúra hagyott implantátumok bőrirritációt, míg a túl rövid, a corticalis szintjét éppen csak meghaladó fémvégek kivételi nehézséget, ínsérülést okozhatnak.

A műtétet követőn a végtagot néhány napig palmaris gipszsínben, majd rövid tépőzáras brace-ben rögzítjük. A külső rögzítés általában 1–2 hét, de legkésőbb 4 hét után teljesen elhagyható.

Fémkivétel a teljes radiológiai konszolidációt követően javasolt narkózisban vagy helyi érzéstelenítésben, leghamarabb 6–8 hét után, általában 3–4 hónapos korban (*2–3. ábrák*).

1. ábra

Repozíció tompa végű tűződróttal. A törési résbe dorsalis irányból vezetett tompa végű eszközzel a distalis darab ráemelhető a proximalis törtdarabra

2. ábra

3. ábra

2-3. ábra

Dia-metaphysealis határon elhelyezkedő, illetve distalis metaphysis régióban kialakult radius törések kezelése kettős szegezéssel. Az ulna egyidejű törése miatt mindkét esetben annak szegezése is megtörtént, a szintézis így mozgásstabillá válik

Módosított, lágyrészvédővel ellátott rövid szegezés egy implantátummal

A műtéti technika kezdeti lépései megegyeznek a kettős szegezésnél leírtakkal. Fontos különbség, hogy a műtét itt mindig vértelenítő mandzsetta használata mellett történik, hogy a lágyrész védő behelyezése során az inakat ne sértsük.

A repozíciót követően a physistől proximalisan, dorsalisan a középvonalban másfél cm-es haránt metszést ejtünk. Az extensor inakat látótérbe hozzuk, a velőűr megnyitása az inak között, a radius középvonalában történik. A distalis darabba a korábbiakban leírt módon vezetjük be az előrehajlított szeget, úgy hogy a konvexitás palmaris irányba tekint. A repozíciót és a szeg pozícionálását követően a szeg végét úgy vágjuk le, hogy nagyjából 1 cm-es szakasz maradjon szabadon. Az inak széthúzása és egyértelmű láthatóvá tétele után lágyrészvédő, menetes végű Endcapot® csavarunk a szeg végére. Az Endcap® nem haladhat át a physisen, és nem is érintheti azt.

Egyidejű ulnatörés esetén itt is elvégezzük az ulna konvencionális, proximalis irányból vezetett anterográd velőűrszegezését.

A műtét végén a bőrt az Endcap® felett zárjuk. Ha az Endcap ® a bőrt nagyon előboltosítja, vagy feszülést okoz, akkor azt célszerű inkább eltávolítani és a szeget rövidebbre vágni, vagy mélyebbre helyezése után ismét rácsavarni (*4–5. ábrák*). Az utókezelés hasonló a fentiekben leírtakhoz.

4. ábra

5. ábra

4-5. ábra

Lágyrészvédővel (Endcap ®) ellátott szegezés. A lágyrészvédő a physist nem érinti. A szeg bevezetési pontjának gondos meghatározásával még az egészen kis metaphysis darabbal rendelkező törések is stabilizálhatóak

ANYAG ÉS MÓDSZER

2013. október és 2017. október között, két centrumban, összesen 84 gyermek rövid kettős elasztikus szegezését végeztük el, míg 16 esetben lágyrészvédővel ellátott mono-elasztikus szegezés történt. Valamennyi műtét Synthes TEN®, illetve Endcap® implantátumokkal történt. A műtéti indikáció valamennyi gyermeknél zárt, az alkar distalis harmadára lokalizálódó, nagy diszlokációval, és mindkét corticalis átszakadásával járó metaphysis vagy dia-metaphysealis átmenetben elhelyezkedő törés volt. A physisek valamennyi esetben nyitva voltak, a gyermekek életkora 4–14 év között volt. A törések közül valamennyi zárt volt. A műtéteket összesen hat, gyermektraumatológiai ellátásban tapasztalt gyermeksebész, vagy traumatológus szakorvos, illetve szakorvosi asszisztencia mellett szakorvos jelölt végezte.

EREDMÉNYEK

Sem a kettős szegezéssel, sem a lágyrészvédelemmel ellátott mono-elasztikus szeggel ellátott csoportban nem került sor reoperációra. Implantátum vándorlás nem alakult ki. Mély szeptikus szövődményt egy esetben sem észleltünk.

Három esetben felületes infekció alakult ki a kettős, egy esetben a monoelasztikus szeggel ellátott csoportban, a szegek eltávolítását követően a panaszok megszűntek, a törés az eltávolítás idején már konszolidált.

A kettős elasztikus szeggel ellátott csoportban, összesen további 9 gyermeknél észleltünk az implantátum vég által okozott bőrirritációt. A fémek eltávolítása után ezek a panaszok maradéktalanul megszűntek. A lágyrészvédelemmel ellátott csoportban implantátum okozta irritációt nem észleltünk. Ín-, illetve idegsérülést egyik csoportban sem találtunk. Az implantátumokat a 6–24. hét között – egy kivételével – minden gyermekből eltávolítottuk. Egy esetben a túl mélyre került implantátumot nem tudtuk kivenni.

Az utánkövetési idő 9 hónaptól 4 évig terjedt, valamennyi gyermek teljes, oldalazonos funkcióval gyógyult. Mozgásbeszűkülés, kései növekedési zavar egy gyermeknél sem alakult ki (*6. ábra, I. táblázat*).

A műtét után közvetlenül, a negyedik héten, illetve fél éves korban, fémeltávolítás után készült röntgenfelvételeket elemezve az alábbi eredményekre jutottunk:

A posztoperatív szakban (0–1. hét) végzett röntgenképeket anatómiainak tekintettük, ha mind AP, mind oldalirányból a maximális tengelyeltérés 5 fok alatti, jónak, ha 15 fok alatti volt, elfogadhatónak 30 fokig, ha az életkort is figyelembe véve a remodellációs határ alatti volt, illetve rossznak, ha a tengelyeltérés értéke nagyobb volt, mint a várható remodellációs potenciál.

A kettős szegezéssel ellátott csoportban 70 gyermeknél anatómiai, 13 gyermeknél jó, 1 gyermeknél elfogadható helyzetet állapítottunk meg. Az Endcap®-val ellátott csoportban, 13 esetben anatómiai, 3 esetben jó eredményt találtunk. A kettős szegezéssel ellátott csoportban, a négyhetes korban végzett kontrollröntgen némileg rosszabb radiológiai eredményt mutatott: 4 gyermek besorolása az anatómiai helyzetről jóra, 3 gyermek helyzete a jó besorolásról elfogadhatóra változott, míg egy gyermeknél rossz kategóriát állapítottunk meg. A féléves kontroll során készült felvételen ugyanakkor, a remodellációs szak lezajlását követően, egy kivétellel, valamennyi esetben anatómiai tengelyállást észleltünk. Ez utóbbi betegnél is, az egyéves radiológiai kontrollvizsgálat már jó helyzetet mutatott.

A lágyrészvédővel ellátott csoportban nem észleltünk változást a néhány hetes posztoperatív és féléves radiológiai felvételek elemzése során (*II. táblázat*).

6. ábra
Friss műtéti hegek, illetve 1 éves posztoperatív funkció

I. táblázat Szövődmények a kettős illetve mono-elasztikus szegezéssel ellátott csoportokban

Kettős elasztikus szegezés	n=84	Monoelasztikus szegezés Endcap rögzítéssel	n=16
Bőrirritáció	9	Bőrirritáció	0
Rediszlokáció	1	Rediszlokáció	0
Felületes infekció	3	Felületes infekció	1
Mélyinfekció	0	Mélyinfekció	0
Ín- vagy idegsérülés	0	Ín- vagy idegsérülés	0

II. táblázat A műtétek után a röntgenfelvételeken észlelhető tengelyeltérések változása a remodelláció során különböző időpontokban

Kettős elasztikus szegezés N=84	1. hét	4. hét	24. hét	Mono-elaszikus szegezés Endcap rögzítéssel N=16	1. hét	4. hét	24. hét
Kiváló (max. 5 fok tengelyeltérés)	70	66	83	Kiváló (max. 5 fok tengelyeltérés)	13	13	16
Jó (max. 15 fok tengelyeltérés)	13	17	1	Jó (max. 15 fok tengelyeltérés)	3	3	0
Megfelelő (max. 30 fok tengelyel-térés a remodellációs határon belül)	1	0	0	Megfelelelő (max. 30 fok tengelyeltérés a remodellációs határon belül)	0	0	0
Rossz (esetleges remodellációs határon túli eltérés)	0	1	0	Rossz (esetleges remodellációs határon túli eltérés)	0	0	0

MEGBESZÉLÉS

A diszlokációval járó gyermekkori distalis radius törések kezeléséről nem találhatóak magas szintű evidenciák az irodalomban (2). Konzervatív kezeléssel többnyire az elmozdulás nélküli, illetve a legalább egyik periosteum intaktságát megtartott törések kezelhetőek problémamentesen (2, 16, 22). A műtéti eljárást – az elmúlt negyven évben – a tűződrótos osteosynthesis, illetve ennek számos variációja jelentette (16, 22, 25). Egyes szerzők csak sikertelen konzervatív kezelést követően (első hetekben észlelt remodellációs kapacitást meghaladó rediszlokáció), mások a nagyfokban instabil törések esetén már primeren javasolnak műtétet (2, 16, 22).

Nem egyértelmű a remodellációs kapacitás határa sem. A 15 fok alatti elmozdulás a fiúknál 12, illetve lányoknál 10 éves kor alatt biztosan elfogadható, az ennél nagyobb, 30–40 fokig terjedő angulációval járó metaphysis törések remodellációs kapacitásáról ugyanakkor megoszlanak a vélemények (6, 9, 13). A mindkét periosteum átszakadással és megrövidüléssel járó esetekben a rediszlokációs arány még sikeres primer fedett repozíció esetén is 40–50 % lehet (2, 16, 22).

A gyermekkori distalis diszlokált radiustörések ellátására alkalmazott tűződrótos osteosynthesis nem problémamentes módszer. A szintézis további gipszrögzítést tesz szükségessé, így a gyermek az operatív és konzervatív kezelés hátrányait is elszenvedi. Áttekintve a 2009 és 2014 között az osztályunkon operált eseteinket, meglehetősen magas szövődményarányt észleltünk. Hasonló eredményeket találunk az irodalomban, ahol igen magas, akár 20–40%-os műtéti szövődményarányokról számolnak be. Ezek nagy része minor szövődmény, bőrirritáció, felületes infekció, de osteomyelitisszel szövődött mélyinfekciókról, iatrogén Galeazzi sérülésről, illetve reosteosynthesist szükségessé tevő rediszlokációkról is találhatóak beszámolók (5, 7, 17, 20, 21). A problémák nagy része ugyan további ellátás keretében kései szövődmények nélkül megoldható (ismételt, illetve prolongált gipszrögzítés, reosteosynthesis stb.), az alkalmazott terápia elhúzódása, a végtag hosszabb immobilizációja, illetve a szükséges kontrollvizsgálatok számának növekedése jelentős időbeli és anyagi terhet jelent, mind a gyermek, mind a család számára. Annak ellenére, hogy nincs egyértelmű bizonyíték arra, hogy a növekedési zónán átvezetett Kirschner–drót növekedési zavart okozna, a legtöbb szerző javasolja azok lehetőség szerinti elkerülését tűzés során, illetve a dia-metaphysis átmenetben észlelt törések trans-physealis szintézise után, hosszú távú utánkövetést a physisek állapotának ellenőrzésére (1, 15, 18).

Az elmúlt években megjelent néhány tanulmány, amelyek során distalis alkartöréseket a physiseket elkerülő elasztikus velőűrszegezés módosított formáival látták el, de ezek az eljárások is kivétel nélkül igényelnek posztoperatív 4–6 hetes gipszrögzítést (3, 4, 10, 12).

Célunk egy olyan műtéti módszer kidolgozása volt, amely a növekedési zónák megkerülésével, minimál invazív módon, mozgásstabilan biztosítja az elért helyzetet. Az általunk alkalmazott technika a klasszikus ESIN módszer minimális módosításokkal. A biomechanikai elvek lényegében ugyanazok, mint a csöves csontok diaphysis töréseinél alkalmazott hosszú szegek esetében: a csontcorticalis belső rögzítése az előre meghajlított szeggel úgy, hogy a törés szintje a szeg legnagyobb görbületére essen.

A radius klasszikus elasztikus velőűrszegezése esetén az előre hajlított szeg legnagyobb görbülete a diaphysis magasságában helyezkedik el, így a legnagyobb feszülést a distalisan elhelyezkedő töréstől excentrikusan fejtené ki. A „C"-alakban meghajlított mini szegek esetén a görbület a törés magasságába kerül, így stabilizáló hatását is itt fejti ki.

Az axialis, illetve rotációs stabilitás eléréséhez szükséges a két, különböző pontokról indított, relatív vastag szegek alkalmazása. Gyermekkorban a radius distalis végének a remodellációs kapacitása a növekedési porcok épsége esetén kitűnő. A szintézis során ugyan anatómiai repozícióra törekszünk, de bizonyos fokú tengelyeltérés megengedhető. Az irodalomban általában gyermekkori radius distalis vég törések 15 fok alatti értékét a legtöbb szerző elfogadhatónak tartja. Amennyiben a műtét után ennél nagyobb tengelyeltérés nem alakul ki, a remodelláció általában teljesen végbemegy. Az eseteink egy részénél a közvetlen műtét utáni időszakban készült röntgenfelvételek mérsékelt tengelyeltéréseket igazoltak, ugyanakkor fél évvel később ezek mind korrigálódtak. Egy esetben észleltünk nagyobb tengelyeltérést a remodellációs határ közelében, itt reszintézist nem végeztünk, a remodellációs folyamat itt is végbement, de egy évet vett igénybe, a klinikai funkció a harmadik hónaptól ugyanakkor teljes volt.

A szegek bevezetési pontjai (Lister tuberculum és a radius distalis lateralis vége) megfelelnek a radius velőűrszegezésnél használható standard behatolási zónáknak. Bár anyagunkban ín, illetve idegsérülést nem tapasztaltunk, a két bevezetési ponton való áthaladás több szövődmény forrása is lehet (24). *A dorsalis bevezetés a Lister tuberculumon keresztül az extensor pollicis longus ín sérülését, a radialis behatolás a nervus radialis érzőágának laesióját okozhatja. Bár irodalmi adatok és saját, alkar diaphysis törések műtétei során szerzett tapasztalataink alapján is ezeknek a szövődményeknek az esélye alacsony (1–2% alatti), a kettős szegezési technikával elvileg növelhetjük előfordulásukat. Az ínsérülés kiküszöbölésére több megoldás is ismert. A szeg bevezetési pontjának meghatározása történhet intraoperatív szonográfia segítségével, illetve vértelenségben végzett műtét során a Lister–tuberculum feletti kis feltárással direkt láthatóvá tétel mellett (23).* A két szeg együttes alkalmazásának további hátránya lehet a bőr irritációja. Anyagunkban ez az esetek 9%-ában fordult elő, és bár minor szövődménynek tekinthető, a gyermekek komfortérzetét jelentősen rontja.

A fentiek miatt vezettük be a technika egy módosított formáját, amikor a rövid elasztikus szeg végére menetes lágyrészvédőt helyezünk. Az Endcap® zárókupak főleg tibia, illetve femurtörések szegezésénél használatos, az összecsúszás gátlása, a stabilitás fokozása, illetve lágyrészvédelem szempontjából. Alkartáji töréseknél való használata kevésbé terjedt el, egyes szerzők felnőttkori alkartáji törések ESIN technikával való stabilizálása során alkalmazták.

Az alkar distalis végén való alkalmazásához a korábban említett kis feltárás ennél a technikánál mindenképpen szükséges az inak közelsége és a relatív nagy implantátum méret miatt. Eddigi eseteinknél úgy találtuk, hogy a menetes végű Endcap® stabilitás fokozó hatása a második szeget feleslegessé teszi és a bőr irritációját teljesen megszünteti.

A posztoperatív külső rögzítés során rövid gipszsínt, illetve tépőzáras műanyag brace-t alkalmaztunk. Ez az átmeneti külső rögzítés inkább a kisebb gyermekek esetén volt szükséges, főleg a komfortérzet javítása céljából, de az esetek 70 százalékában a második hét után teljesen elhagyható volt.

Vizsgálatunknak több gyenge pontja is akad. Egyelőre hiányoznak a prospektív randomizált vizsgálatok, amelyek a fenti technikák előnyeit egyértelműen igazolnák a hagyományos tűződrótos eljárással, illetve a szintén osztályunkon bevezetett módosított hosszú elasztikus velőűrszegezéssel szemben. Nincsenek biomechanikai adataink az egyszeres Endcap-pal ellátott szeg, illetve kétszeres szegezés stabilitásának erősségéről. (Jelenleg folyamatban van egy biomechanikai vizsgálat, amely az egyes szintézisek stabilitását hasonlítja össze.) A fenti technika valódi szövődmény arányairól csak a tanulási görbe időszakát is figyelembe vevő, jóval nagyobb esetszám elemzése után alkothatunk pontosabb képet.

KÖVETKEZTETÉSEK

A fenti hiányosságok ellenére úgy gondoljuk, hogy az általunk bevezetésre került rövid szegezési technika jó alternatívája lehet az eddigi standard eljárásnak. Legfőbb előnyének a physisek elkerülését, a mozgásstabil szintézis elérését, a csökkent idejű és egyszerűsített külső rögzítést, és a gyermekek gyors rehabilitációját tartjuk. A sikeres műtéti technika az ESIN technikában, illetve gyermektraumatológiában való jártasságot igényel. További tapasztalatainkról nagyobb esetszám, megfelelő összehasonlító klinikai és biomechanikai vizsgálatokat követően fogunk beszámolni.

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